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Pavement Markings – Back to Basics

Technology Status and Action Plan

Ontario
Ministry of Transportation
Research and Development Branch

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Pavement Markings – Back to Basics
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Abstract:	The status of pavement marking technology has been assessed based on comprehensive literature search, review of in-house technology and practices, and information collected from other user agencies as well as pavement marking material manufacturers and suppliers. The study has shown that conventional, modified alkyd traffic paint is still the most widely used pavement marking in spite of the emergence of alternative marking materials with much superior performance. Described are not only the various new and highly durable pavement markings but also advancement in technology and methodology related to conventional traffic paints: their selection, specification, and procurement procedures. An action plan has been prepared based on this critical assessment and also based on identified Ministry needs and priorities. The presented action plan is designed primarily to access available technology and "know how". However, a mechanism is also proposed for new technology development and introduction of the more promising new pavement marking materials such as field reacted epoxy and polyester systems.
Key Words:	pavement markings, durable paints, paint application, reflective glass beads, paint pigments, paint solvents
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G.J. Kennepohl
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Published by
The Research and Development Branch
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1. INTRODUCTION

1.1 Background

The safety benefits of pavement markings in providing guidance, regulatory, and warning information to the driver, have been well recognized and accepted since their introduction in the late 1920's and early 1930's [1-4]. The original drying oil-based paints and the later alkyd resin-based oil paints served well in the early days of motoring. In many areas, including Ontario, alkyd paint is still the old standby and the prime source for pavement markings, mainly because of the low initial cost and a well established application procedure using automated and motorized spray equipment.

In recent years, however, problems with the durability and wear of conventional traffic paints increased significantly in Ontario and elsewhere [5-9]. This concern is reflected by an increase in the number of *Research & Development Need Statements* received from different Ministry Branches and Districts throughout the Province. The Materials Research Office undertook a research project to take a fresh look at all facets of the Ministry's pavement marking practices. The reason and justification for this project are based largely on the following key observations:

1. Today's pavement markings must provide greatly improved performance in terms of durability as well as day and night visibility in order to provide the necessary safety features for highways with increased traffic volumes, density, and speed.
2. New pavement marking technologies must be assessed and obtained in order to exploit potential benefits from new developments for safety and life-cycle cost optimization.

Since the Province of Ontario is currently spending in excess of $7.0 million annually on pavement marking of which about half is for the cost of materials alone, any significant technology improvements will have a major impact on cost benefit. To identify a strategy for future action, the Research and Development Branch started, in February 1987, a project entitled *Pavement Markings – Back to Basics* (R&D Project 22174) in concurrence with the Highway Operations and Maintenance Division as the main client. Since the Province is traditionally in a leadership position in matters of material standards and specifications, the results of this project will also impact on the municipalities and the private sector of Ontario.

A brief outline of the project work statement and an overview of the objectives and organization of this report are given in the following sections.

1.2 Project Work Statement

Specific problems that led to the identification of research needs in pavement markings and subsequently to the initiation of this research project work statement include:

Technical

- wear and durability poor,
- loss of reflectance at night or on wet pavement,
- higher bead retention required,
- variation in composition and consistency gives rise to application problems,
- drying times for some applications are too long, and
- no reliable accelerated test method.

Operational

- traffic paint specifications and tender procedures need improvement,
- currently no documented specification or guidelines for new pavement marking materials,
- turnaround time for product testing and approval is too long,
- inspection and quality assurance are not geared to improving performance,
- need for a reliable life-cycle costing model,
- poor overall economics,
- lack of coordinated and concerted effort to keep in step with new developments.

The two main objectives of this project are:

1. To generate ideas on approaches to improving existing materials and application methods.
2. To look beyond the constraints of present materials, equipment, and practices toward what would constitute the optimum marking or pavement delineation system.

The scope of the project is broad and covers conventional traffic paint as well as new, more durable pavement marking materials including aspects of equipment, application procedures, specifications, quality control/assurance methodology, and economics. Excluded from this project are temporary pavement markings, removal of pavement markings, and raised pavement markers.

The project work consists of: a) the determination of the technology status, and b) the development of an action plan. The individual tasks are summarized in Figure 1 and were scheduled to be completed within a period of six months. A more detailed description has been documented in the minutes of the monthly project review meetings.

1.3 Objectives and Organization of the Report

The key objectives of this report are to reference and document existing and available pavement marking technologies, to make a critical assessment of current experience and practices and to use this information as a basis for recommending future action plans for the Ministry.

Information about the available and practiced technology has been gathered through a state-of-the-art literature search, in-house records and expertise, as well as contacts with other user agencies and product suppliers. The key findings and observations are outlined in sections 2 to 4. The critical assessment of current available pavement marking systems, shown in Section 5, is based on a priority rating which was developed jointly with the Chemical Section, Maintenance Operations Office, Traffic Management and Engineering Office, and the Equipment Engineering Office. A proposed action plan is outlined in Section 7.

OBJECTIVES	TASKS
1. Determine Status of Technology	A) Information Gathering - state-of-the-art literature search in-house technology - outside contacts B) Critical Assessment of: - materials, ie. advantage/disadvantage of conventional and new paints/or pavement markings - validity of product specifications - equipment needs and application procedures - R & D needs - economics C) Interim Report: Status of Technology
2. Develop Action Plan	A) Identification of Needs and Priorities for: - internal line of command/communication - procedure for product approval-acceptance - procedure for designation of suppliers - conventional traffic paints and equipment - new development in pavement markings - technology transfer and training - cost benefit analysis B) Development of Proposals ie. specific proposals for identified needs C) Selection of Program ie. prioritize proposed projects and recommend program D) Final Report: Action Plan

FIGURE 1: THE PROJECT WORK

2. LITERATURE SEARCH

2.1 Overview

The information in this section has been gathered mainly from reports and references listed in the Dialog Search, a computerized information retrieval service [10]. The three data bases examined were:

- COMPENDEX: produced by Engineering Information Inc.
- TRIS: Transportation Research Information Service
- NTIS: National Technical Information Service

Another listing of reference materials included the comprehensive bibliography for the Roadway Delineation Practices Handbook [1]. Several other general references used consisted of encyclopedia and science texts [11-13] that contained information on many historical and compositional characteristics of pavement marking materials.

Paint has been used for many centuries. During the 1920's, it became necessary to use oil-based paint to mark the roads that automobiles travelled along. Some of the oils used were linseed, soya, safarin, tung, oiticica, and perilla. Alkyd paints were developed in 1927 and have become today's old standby, and the most popular type of paint.

Due to alkyd's low durability and today's increased traffic, there has been a need to develop more durable markings. Over the past 50 years many ideas have been formulated. Only a few of these may be good enough to replace alkyd paints cost effectively. The most viable alternatives have been incorporated into the classification system in the following section.

2.2 Classification of Pavement Markings

In the past, pavement markings have been classified both by resin type and by process of application. Other classifications involve the reflectance (i.e., with or without glass beads) and drying time (i.e., coning and non-coning).

For this project, marking materials will be classified primarily according to the application process with subcategories for the various resin types, reflectance and drying time. Because several of the common resin types are employed in different marking systems, classification by resin type alone does not uniquely describe the entire range of materials

available. Therefore, the classification by process of application also used by New York State is preferred [4]. A classification of pavement markings by process of application with four main categories (A to D) is outlined in Table 1. The mode of application for these four classes of basic processes and materials is as follows:

Class "A" Traffic Paints: All the components are carried in a solvent and the paint remains liquid as long as it is sealed. Traffic paints are almost always applied by spraying, although brushes or rollers may occasionally be used. The solvent evaporates after application and the vehicle solids resin form a solid paint film.

Class "B" Thermoplastics: The resins used in these markings have thermoplastic properties, i.e. melting at elevated temperatures and solidifying at ambient temperature. The molten material is applied to the pavement by extrusion or spraying and then cools to form a solid marking.

Class "C" Preformed Tapes: These markings are fabricated as roll or sheet stock in a factory or as cutout legends. The preformed markings are installed by using either a pre-applied adhesive on the marking or an adhesive applied to the pavement.

Class "D" Field-Reacted Materials: Two or more components – a resin and a hardener – are mixed just before or during application to the pavement. A chemical reaction then occurs to form a solid resin. Application is by spraying, and mixing of the two components may be internal or external to the spray equipment.

2.3 Traffic Paints (Class "A")

2.3.1 Modified Alkyd

Alykd resins consist of polyester formed by repeated reactions between polyhydric alcohols and di- or polybasic carboxylic acids. A common reaction involves glycerols as the alcohol and phthalic anhyride as the dibasic component [12]. The fundamental esterification reaction occurs as follows:

$$\underset{\text{Alcohol}}{ROH} + \underset{\text{Acid}}{HOOCR'} \rightarrow \underset{\text{ester}}{ROOCR'} + H_2O$$

TABLE 1: CLASSIFICATION OF PAVEMENT MARKINGS

CLASS	MATERIAL	RESIN TYPE	DRYING TIME
A	Traffic Paint	. modified alkyd	coning non-coning
		. chlorinated rubber	coning non-coning
		. water based	coning
		. epoxy	non-coning
B	Thermoplastics	. alkyd . hydrocarbon . epoflex	
C	Preformed Tapes	. plastic . foil	non-coning non-coning
D	Field Reacted Materials	. epoxy . polyester	

Traffic paint is comprised of a binder (alkyd resin), solvent, pigments, and other substances such as driers, fillers, stabilizers, and plasticizers. The typical formulation for alkyd paint is as follows:

Pigment	55%
Alkyd Resin	15-20%
Solvent	25-30% (by mass)

Driers, stabilizers, fillers, and plasticizers make up the rest of the formulation but only comprise a very low percentage of the total mass.

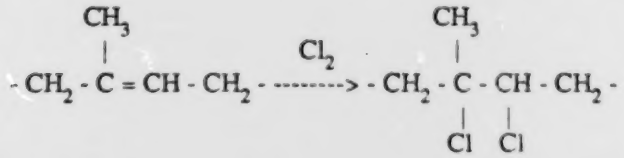
Ever since the initial synthesis of alkyd resins in 1927, the popularity of alkyd paints has increased to the point where they are the most widely used traffic marking material today. A few factors that effect the performance of alkyd paints were evaluated by many States since 1980. The conclusions were compiled by FHWA into a single report in 1984 [14]. The optimum rate of glass bead application was found to be 0.4 kg/L (4 lb/gal), although it could be as high as 0.6 kg/L (6 lb/gal). An applied thickness of 280 μm (11 mils) wet was recommended so that a dry thickness of 130 μm (5 mils) could be achieved. Polyester beads were also tested for reflectivity and it was discovered that their performance was equal to the performance of glass beads. Straight substitution of the two types of beads was considered acceptable. Another point mentioned was that air pollution is produced by hydrocarbons released during the application and drying of the paint.

The City of Calgary, Alberta produced a report of pavement markings which contained the results of their alkyd paints' performance [15]. As advantages, it lists the ease of application, use of existing equipment, low initial cost, excellent colour, and excellent night time reflectivity. There were shortcomings, such as the short life, which caused more than one application per year and sometimes made year round delineation impossible.

For the past decade, New York State has been using hot applied modified alkyds. There is a 20 to 60 second drying time which depends on the formulation and application temperature. Consistently, New York's alkyd paints are the poorest performers when compared to acrylic, epoxy, latex, or chlorinated rubber paints. None of these paints have approached the life span of chlorinated rubber paints. The primary mode of failure of alkyd paints appears to be abrasion. In the past few years, the abrasion wear increased due to the salting and sanding during the winter months [9].

2.3.2 Chlorinated Rubber

Natural rubber possesses many desirable properties even though it was unsuitable for use as a binder in paint until the 1930's. During the 1930's, chemists produced the first high quality chlorinated rubber that was used in the manufacture of lacquers. Soon after, it was being used in paints and contained between 65% and 67% chlorine. The chemical reaction that combines the rubber with the chlorine is outlined below [12]:



isoprene polymer — chlorine — chlorinated rubber

A typical formulation for chlorinated rubber paint as used by New York [18] is as follows:

	Minimum	Maximum
Pigment, % by wt.	48.0	50.0
Vehicle, % by difference	50.0	52.0
Wt./gal, lbs	11.9	
Non-Volatile Vehicle, % by wt.	41.0	
Total Solids in Paint, % by wt.	69.5	

The pigment contains such substances as titanium dioxide, magnesium silicate, calcium carbonate, and zinc oxide. Chlorinated rubber, chlorinated paraffin, and an alkyd resin comprise the non-volatile vehicle. The remainder of the paint is methyl ethyl ketone (MEK) which is a strong smelling solvent.

In June of 1970, New York State documented several tests that took place in the late 1960's [16]. The tests involved many types of markings including a modified, alkyd-chlorinated rubber combination. It was concluded that the combination paint performed as well as the standard modified alkyd paint in use at that time. However, because the cost of the standard modified alkyd paint was $0.50 less a gallon, New York [5] did not use the chlorinated rubber paint formulation.

The State of Kentucky used a trial application of chlorinated rubber based paint during its 1982 striping season [17]. They applied it with a 380 μm (15 mil) wet thickness and it would dry to an 200 μm (8 mil) thickness. During the one year period following, they experienced no durability or appearance problems. In fact, they rated the appearance as good.

Much later, in 1984, the City of Calgary's Department of Transportation examined chlorinated rubber paint and found the useful life to be approximately eight months. Their initial cost was $0.16 per lineal foot. No conclusions on the future use of chlorinated rubber were made at this point [15].

Over three thousand gallons of chlorinated rubber traffic paint were installed by New York State maintenance personnel to compare its workability and durability to the Department's standard modified alkyd traffic paint [18]. Successful installation of the chlorinated rubber paint was achieved with only minor modifications to normal equipment and procedures. "No-track" times of three to six minutes, compared to about one minute for modified alkyd paint, required greater efforts to minimize traffic damage to chlorinated rubber paint lines during striping. The strong smelling MEK solvent used in the chlorinated rubber paint caused worker concern, but a review of the available safety data indicated both this solvent and the toluene normally used in the modified alkyd paint require similar safety precautions. Yield calculations after completion of striping indicate that chlorinated rubber paint was applied at an average film thickness of 318 μm (12.5 mils), compared to 409 μm (16.1 mils) for modified alkyd control sections. In spite of this, the durability of the two paints was similar. It appears that chlorinated rubber paint placed at a wet film thickness of 380 μm (15 mils) can provide year round durability on many low volume state highways. However, its long "no track" times make it difficult to apply in many locations.

Chlorinated rubber paints were consistently the best performers in an accelerated wear test in New York [9]. Many other types of paint such as alkyd, acrylic, epoxy, and water-base were involved in the test. All of the New York and New Jersey State chlorinated rubber formulations except one used MEK as the solvent. The other solvent used was toluene. A slow drying time was the major problem plaguing this type of paint. The predominant mode of failure experienced by the chlorinated rubber was abrasion. At the failure point of the marking which, in New York State, is a minimum durability rating of 5 and a minimum reflectance of 140 mcd per lx per m^2 over 50% paint loss was attributed to abrasion.

Because of continuous improvement, chlorinated rubber paints are gaining wider acceptance. Thus the State of Missouri has developed a fast dry chlorinated rubber paint for state wide use. The State claims a cost of approximately two cents per foot in place and a drying time of 10 minutes.

2.3.3 Water-Based Paints

Emulsion or water-based paints have evolved a great deal since they were first used by the Egyptians to seal their boats. After the 1920's, there were many improvements made to the water-based paint formulations. They were introduced to North America in 1948 [12]. The term latex paint was originally used for a water-based emulsion of styrene-butadiene copolymers.

The composition of a typical acrylic resin based emulsion paint used by New York Department of Transport [16] includes the pigment and vehicle in the following proportions:

Pigment	50.7%
Vehicle	49.3%

For a full set of laboratory tests, including the pigment and vehicle analysis, see Table 2. Another resin used for water-based paints is the styrene-butadiene resin.

The main feature of water-based paints is that they are designed to be environmentally safe, i.e., the volatile matter is mostly water. Most pigments used are inert or contain no lead in order to also make the pigment portion of the paint environmentally safe.

During the mid 1960's, the State of New York applied heated and unheated water-based paint to roadways [16]. They concluded that it would not be a suitable substitute for their standard alkyd paint because the useful life did not exceed three and four months on bituminous and concrete pavement respectively. The markings applied at ambient temperatures seemed to perform better than the heated ones. There was a little hesitation in coming to this conclusion due to the very short service lives of both markings.

Shortly after, the California Department of Transport reported the results of a test section which involved water-borne paints [3, 14]. The poor characteristics were the wet visibility, durability, and the application problems due to wet pavement and weather. Other better

TABLE:2 LABORATORY TEST RESULTS FOR
FLAT WHITE ACRYLIC RESIN-BASE EMULSION PAINT (16)

TEST	RESULT
Composition	
Pigment	50.7%
Vehicle	49.3%
Pigment Analysis	
Titamium Dioxide	19.2%
Inert or Extending Pigment	80.8%
Vehicle Analysis	
Volatile Thinner and Drier	70.6%
Fixed Drying Oils and Resins	29.4%
Consistency	76 KU
Bleeding	Satisfactory
Water Resistance	Softens
Drying Properties	
Tack-Free	20 minutes
At 1 hr.	Satisfactory
Water Resistance (Film Loss) After 7 Days	
Dried Film	45 mg
Water-Immersed 18 hr.	77 mg
Weatherometer, 100 hr.	Satisfactory
Abrasion Loss at 100 hr.	49 mg
Flexibility	Satisfactory
Accelerated Settlement	7 minutes
Skinning	Satisfactory
Wet Hiding Power	Satisfactory

characteristics were mentioned such as its good day/night colour, compatibility with existing equipment, and its lack of toxicity.

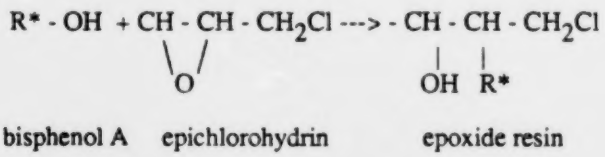
Another set of tests were examined in New York State during 1987 [9]. The performance of the latex paints was improved to about the quality of New York's standard alkyds. Any improvements over the alkyds were generally less than 50%. The main failure mechanism was chipping and approximately 65 to 70% of the marking was lost in this manner.

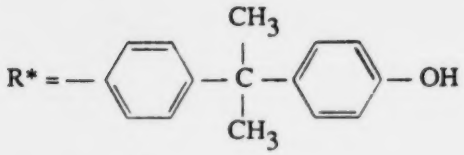
Water-borne (latex) paint is now found in most of Southern California. During the 1984 season, California used 243,000 gallons of water-based paint. Ever since there has been a steady increase in latex paint usage. More than half the traffic paint used in California in 1987 will be water-based.

Most formulations are based on acrylic or latex resins and have a drying time of around 10 minutes. California has developed a lead-free yellow pigment system for the water-based paints. It can be applied hot or cold and has no solvent odour. In comparison to solvent-based paints, the water-based paints have better bead retention. Another attractive feature of water-based paint is that it is safer to handle and store. The toxicity of water-based paint is fairly low by current environmental standards.

2.3.4 Epoxy

Epoxy resins were first produced in 1947 and have been used in paint formulations ever since [13]. Most epoxy is made from a mixture of bisphenol A (diphenylolpropane) and epichlorohydrin (epihalohydrin) in varying proportions. The formation of the epoxy resin is given below:





The Minnesota Department of Transport did extensive testing of epoxy markings starting in 1969. Later, in 1975 and 1976, the State laid 140 million lineal feet of epoxy paint on high volume roads and another 800,000 lineal feet on rural and urban roads [14].

Where the bond failed, it was usually because the epoxy was applied to a contaminated surface. If the application was good, and was 15 mil thick, the marking could last for two winters even though snowplowing, salting, and sanding are all part of Minnesota's winter road maintenance. Other benefits are that epoxy applies to Portland cement concrete better than any other marking and a quick, hot application to wet pavement can be achieved. This epoxy paint can be applied in the same manner as regular paint and Minnesota has the technology to build a striper that will apply both materials. Over a two to four year period, it was felt that epoxy would have much lower application cost than regular paints.

After the 1985 painting season, the State of Kentucky prepared a report with their findings on epoxy traffic paint [17]. Once the solvent was added the paint had a shelf life of approximately 10 days. When sprayed at 15 mils thickness wet, it dries to a thickness of 10 mils. At 75°F, drying time was between three to five minutes. During the summer of 1983, Kentucky placed about 1.7 million lineal feet at a cost ranging from $0.09 to 0.13/ft. Performance results showed poor bead retention and poor retroreflectivity.

A few epoxy paint markings were placed by the State of New York in the late 1970's and early 1980's. Around 1985, these markings were evaluated in a report on epoxy markings [19]. Some of the markings were six years old and still providing acceptable delineation on PCC and AC surfaces. One-third of the original markings did not provide acceptable reflectivity and had to be repainted. It was concluded that a larger, longer survey is needed to identify causes of the marginal performance of this type of road traffic marking.

2.4 Thermoplastics (Class "B")

2.4.1 Alkyd and Hydrocarbon

Thermoplastics are polymers that can be heated to a liquid without changing the chemical composition. Therefore, thermoplastics can soften and fuse at high temperatures, then harden again upon cooling.

Alkyd thermoplastics are derived from polyesters. Hydrocarbons are derived from petroleum by condensation polymerization, e.g. phenolic resins.

The alkyd and hydrocarbon thermoplastics consist of approximately the same typical formulation:

Component	Weight %
Resin	20
Calcium Carbonate	48
Titanium Dioxide Pigment	12
Reflective Glass Beads	20

The earliest use of thermoplastics for highway marking occurred in Britain, during World War II, when the thermoplastic markings had a reported service life of two years [7]. Engineers began to place thermoplastic road markings in Texas during the year 1950 [7]. It was discovered that the British formulation of wood rosin, plasticizing oil, and pigment, was too soft and discoloured easily. A harder stripe was made by reducing the plasticizing oil in the formulation, but field testing indicated that the material did not adhere to concrete, cracked in cold weather, and discoloured easily. Further experimentation resulted in changing the plasticizing oils, and the addition of an alkyd resin.

By 1964 many more technological advances with thermoplastics had been made. Better durability was achieved by cleaning the pavement with a power broom, compressed air, or a hand broom. In addition, epoxy resin primer or rubber spray primer increased the durability.

New York now uses extensive quantities of thermoplastic markings, primarily on new asphalt pavements placed under contract. Thermoplastic markings were installed on 80 projects in 1979, and surveyed and reported in 1981 [20].

The installations appeared as bright (after cleaning) as newly laid paint. When the road was wet, the thermoplastic markings were much more visible than paint markings due to the thickness of the thermoplastic markings. The adhesion to concrete surfaces had improved, but still was not as good as the adhesion to asphalt concrete. In 1982 about 2,100 miles of hydrocarbon thermoplastics were placed at an average contract cost of $0.326/ft [4].

By April 1985, New York State was using thermoplastics extensively on asphalt concrete pavement [20]. They are experiencing one to three years good delineation, after which substantial damage seems to occur to most markings. One other observation that has been mentioned before is the superior reflectivity of the white markings.

Minnesota [6] had very poor results with a test section of thermoplastics that were laid down in the mid 1970's. The reflectivity was very low after one winter season and did not meet Minnesota's specifications. Also, after the one winter season the actual stripe was gone showing that it was not very durable. Later tests in Minnesota during February 1984 revealed that a thermoplastic material applied at 762 μm (30 mils) thickness suffered considerably from snow plow damage and traffic wear. This resulted in poor retroreflective qualities after one winter of service, regardless of ADT.

Later on in 1984, hydrocarbon thermoplastics were evaluated in New York, Oklahoma, and Virginia [21]. Several interesting observations were made from these test sites. The epoxy and linseed oil primers worked equally well on asphalt surfaces while the primers used on the PCC pavement also worked well. To provide good durability, a surface dry pavement was important. Stripe wear was approximately 10 mils/year and included stud, traffic, and snowplow wear. There was no correlation drawn between stripe wear and ADT. When the striping did fail, the predominant mode of failure was at the bonding of the leading edges and side edges.

Kentucky was another State experimenting with thermoplastic traffic markings. Their white lines held the reflectivity better than the yellow lines. Other problems were anticipated due to the material inadvertently being placed while at an excessively high temperature. Conversely, no significant durability problems were noted and thermoplastics were recommended for expanded use on lower volume roads [17].

It seems that generally there has been a great deal of success with thermoplastic road markings. As long as the installation is closely monitored, the markings can be expected to have excellent durability and reflectivity for at least three years. The only major problem occurred when thermoplastics were installed on Portland cement concrete. Decreased durability and increased bond failures were experienced.

2.4.2 Epoflex

Epoflex, or ETP, is a short form for "epoxy thermoplastic" which was developed in 1980 by the Southwest Research Institute in San Antonio, Texas. Since ETP is a thermoplastic, it does not undergo a chemical change when liquified by heating. Upon cooling, ETP will regain its original solid state physical properties.

The composition of ETP differs from the alkyd or hydrocarbon thermoplastics mentioned previously. Following is listed a formulation that can be compared to the alkyd/hydrocarbon one previously mentioned [22]:

	White Epoflex % by Wt.	Yellow Epoflex % by Wt.
Solid epoxy resin	35.7 ± 0.5	36.0 ± 0.5
Liquid epoxy resin	23.8 ± 0.5	24.0 ± 0.5
Titanium dioxide	11.9 ± 0.3	—
Lead chromate	—	11.1 ± 0.3
Calcium carbonate	11.9 ± 0.3	12.0 ± 0.3
Glass beads	16.7 ± 0.4	16.8 ± 0.4

Early testing of Epoflex in Texas identified many important factors that affect the useful life of the marking. Temperature was considered the most important. The pavement must be at least 12.7°C (55°F) at the time of application and the thermoplastic temperature must be in the range of 216 to 230°C (420 to 450°F). Air temperature along with relative humidity and snowplow wear have little effect on the adhesion and durability of Epoflex. Application of thermoplastic on Portland cement and old asphalt concrete requires a primer beforehand. In winter, abrasion from cars with studded tires greatly increased the wear.

In 1980, the FHWA had developed an extensive set of specifications for formulating paints that are rigidly followed in the laboratory. Further improvements were made in 1981 by

the FHWA [1]. For climates that included moderate to severe winter conditions, a 50:50 ratio of solid resin to liquid resin yields a flexible material. A 60:40 solid/liquid ratio is suggested for hot, dry summer climates, due to the marking being less succeptable to summer roadfilm pickup.

In Denver Colorado [1], Epoflex was applied to a -5°C surface by elevating the temperature to 251°C (485°F). No problems were noted after one year of full delineation.

The State of Minnesota [1] estimated from performance tests that a line could be repainted five and a half times with conventional paint for the price of one Epoflex application. Therefore, Epoflex would be cost effective if it could last at least six times longer than traffic paint.

During a test that took place in four states (California, Colorado, Minnesota, and Texas) an application problem was discovered. If a pressurized air system is used to atomize the thermoplastic, it tends to cool faster. By the time it has reached the pavement, the temperature may be below the temperature needed for a good bond strength. Some tests done by Caltrans explored all the properties of these road markings. Poor wet visibility was noted in addition to poor performance in snow areas. It also caused bad burns to workers who come into contact with it. The Epoflex formulation lasted three to four times longer than the paint used in the area. In California the low threat to the environment due to its composition was appreciated.

Epoflex costs about $0.17/lineal foot which is approximately twice the cost of alkyd paints but only half the cost of hydrocarbon or alkyd thermoplastics. It is usually applied with a 380 to 500 μm (15 to 20 mil) thickness.

2.5 Preformed Tapes (Class "C")

Preformed tapes were being laid on roadways by the early 1970's. They can be permanent durable markings or they can be designed and used as temporary markings around road construction sites. As their name suggests, the tapes come prefabricated.

There are two main types of backing on the tape: foil and plastic resin. The foil backing underlays a pigmented surface layer with glass beads. Resins, plasticizers, pigments, fillers, and glass beads comprise the composition of the plastic resin tape.

Installation of these types of preformed tape is easy although some minor problems have been noted. The tapes can be inlaid on newly paved asphalt roads to prevent snowplow damage and to prevent the edges from curling up. The tape is rolled over by a car tire, truck tire, or by a pavement roller, to press it into the pavement. Some problems were noted in New York State [23] due to the high temperature of the asphalt just before the final rolling. The temperature is approximately 66°C (150°F) minimum and most tapes cannot withstand temperatures that high. Installation of the tape had to take place separate from the paving train.

Tapes can also be placed on top of the pavement by rolling a vehicle tire over it. The state of Maine [24] experienced only minor problems with a hand application cart when they were testing these striping materials in 1983. When laying double lines, the applicator's tape cutter cuts both tapes if the workman was not careful. This made the installation of solid/skip line combinations difficult.

During the early 1970's, preformed tapes had limited use in New York State [23]. They were used between 1974 and 1982 mainly for intersections, construction markings, and special projects. A test section was evaluated in 1983 and included five brands of pre-formed tapes. Both foil backed tapes and plastic backed tapes were tested during this time period.

Generally, the adhesion to Portland cement concrete and asphalt concrete was good and any early failures could be explained by dirty pavement or cold weather during installation. If traffic travels over the markings, then adhesion is also improved. The abrasion wear is very good unless the tapes have been applied to a road surface that is in poor condition or if foil backed tape has been applied to travelled areas of open graded asphalt concrete.

Plastic preformed tapes lasted from one to five years and foil tapes lasted from one to three years. The durability was rated as very good, but the reflectivity was variable, with some ratings being poor. New York State's report also touched on the point that the tape's high cost could be offset by its durability and its ease of application.

2.6 Field-Reacted Materials (Class "D")

2.6.1 Epoxy

Two component epoxy was a relatively new substance when it was used as a road marking in 1969 by the State of Minnesota [6]. The epoxy consists of a resin and a catalyst (hardener) that can be mixed externally. Each component is 100% solids and must be heated so that it may by sprayed onto the pavement just like paint. The chemical composition of the resin is the same as the other epoxy resins mentioned in Section 2.3.4.

The polymer reacts with the catalyst to harden in an average of ten to fifteen minutes. The dry time is variable with climate and has been found to range anywhere from two minutes to four hours.

The Minnesota Department of Transportation [1] and the H.B. Fuller Co. worked together on the development of a sprayable, two component epoxy resin. Field reacted epoxy will adhere to PCC and AC pavements. In fact, it is one of the few markings that has good to excellent adhesion on Portland cement concretes. Companies involved in the production of the epoxy during the years 1970 to 1973 had to improve the "no track" time, bonding characteristics, and the colour retention.

Since 1975, the FHWA has sponsored a lot of generally successful testing of epoxy paint showing desirable results. It can be applied during damp weather and it has good durability under winter conditions as the epoxy marking can resist abrasion and standard ice control activities.

During the 1975/76 marking season, the Minnesota Department of Transportation laid 140 million linear feet of field reacted epoxy markings [6]. Any failure inherent in these lines was due to unclean pavement surfaces which affected the adhesion properties. At 15 mils thickness, these markings lasted two years. The colour of the marking appeared to darken over the two years and hence tended to be less reflective. At the onset of the project, Minnesota commented that there was a lack of supplier competition.

New York State has used 100% solid epoxy as part of its pavement marking program since 1982 and have experienced satisfactory results. Ohio State [25] has used them since 1976

with excellent results on concrete (seven years service) and poor results on asphalt. Another state, Illinois, started using these markings in 1983/84 [26].

In 1976 the State of Wisconsin started using epoxy markings with no intention of stopping [27]. Problems with materials, equipment, and surface conditions were resolved as they arose. The State of Wisconsin continued to use the 100% solid epoxy and, like Illinois and New York, sees considerable promise in the product. One state in the literature search, North Carolina [28], has experienced major difficulties with epoxy markings and stated that the performance is not satisfactory. North Carolina intends to wait until the industry proves itself before testing them again.

2.6.2 Polyester

Much of the original development of polyester field reacted traffic markings was pioneered by the Ohio Department of Transportation and the Glidden Co. during 1975 [1, 3]. The States of New York and California were also interested in the development and performance of these markings.

Polyesters are formed, as shown in Section 2.3.1, by condensation polymerization of polyhydric alcohols and di- or polybasic carboxylic acids. Also used are unsaturated polyesters which are linear polymeric esters. These are produced by reactions between saturated and unsaturated organic acids containing two carboxyl groups and unsaturated glycols containing two or more hydroxyl groups [13].

Two polyester materials were evaluated during these initial tests. The superior product, Glidden "Romark" performed well for the three year test period while the other polyester material is no longer manufactured.

The polyester system consisted of a stripe 15 mil thick, bead rate of 20 lbs/gal, with a "no track" time of less than one half hour. Faster dry times (8 to 12 min) were achieved at higher temperatures. Application can take place in a cold climate at temperatures as low as –18°C (0°F) but longer dry times can be expected. The bonding to Portland cement concrete pavements was found to be inadequate and indicated that its usage is only for asphaltic pavements. It has been applied over top of existing road markings with no trouble.

Field observations of the polyester indicated that it can last up to two years problem-free unless there is a large volume of traffic [14]. In the case of a high ADT, the lines may only remain for one year which is about four times longer than the alkyd paint markings usually last in the same situation. The appearance of a polyester and a painted line were compared and the following conclusions were made:

1. Polyester markings are more opaque and present a better looking line (daytime) than two coats of paint.
2. Night visibility of polyester is also superior to paint due to the increased number of beads used.

The polyester marking was applied using modified hot-paint stripers. In 1975 the modifications could be achieved for a cost of $4500 to $6000. A 1984 study by the Minnesota Department of Transportation produced exactly the same results as previously mentioned. By 1984, Ohio was the only State that was using polyester paints extensively. Their choice of this stems from the test results obtained from the 1975 test installation.

A major concern with the polyester system is the use of methyl ethyl ketone peroxide (MEKP). MEKP, the required catalyst for polyester marking, is a dangerous substance. Special safety precautions and worker training is required to reduce the safety hazard.

In some places, polyester markings have provided good delineation on roadways. Its initial cost is higher than paint, thermoplastics, or epoxy markings. It is generally agreed that it has poor adhesion to Portland cement concrete pavements and has a very slow "no track" time. Cold climates also have a detrimental effect on the longevity of the marking. Regardless of the above points, it has been shown that the service life is approximately two years unless there is a very large volume of traffic [6].

2.7 Miscellaneous Additives

Three significant components or additives to pavement marking systems, i.e. glass beads, pigments, and solvents, are described and discussed in this section. The emphasis is on important aspects of their development which may impact on future applications.

Glass Beads

The trend towards using traffic paint that was reflectorized with shiny glass beads began in the early 1950's [2]. Much of the initial technology used for glass beads was developed from two studies. Lyon and Robinson did a study in the late 1940's for the Missouri State Highway Department [29], followed by a study by Pocock and Rhodes at the Michigan State Highway Department [30].

Hiss reported in 1966 New York's field experience with glass beads [31]. Index of refraction, bead retention, and increased light reflectivity are discussed in the paper.

Recent fundamental studies at the Pennsylvania State University [32a,b] examined specular reflection and diffuse reflection from spherical glass beads in pavement markings. A first approximation calculation of the radiance (retroreflection) received by the driver is presented.

Glass beads are used for the retroreflectorization of road traffic markings. They are added to traffic paints, thermoplastics, preformed tapes, and field reacted materials. Adding glass beads to road markings is the most common method used for improving the night time visibility. Gradation of glass beads by sieve size is very important.

The size proportions are specified for optimum visibility by the Ontario Provincial Standard Specifications (OPSS) No. 1750.

If various different diameter glass beads are utilized, a more durable and longer reflecting line results. Figure 2, adapted from Rhudy and Ritter [34], shows how a mixture of small and large beads is retained in comparison to only large beads.

In addition to the bead size, the following characteristics are considered important:

- durability
- colour
- bead type and grade
- roundness
- gradation
- refractive index
- imperfections

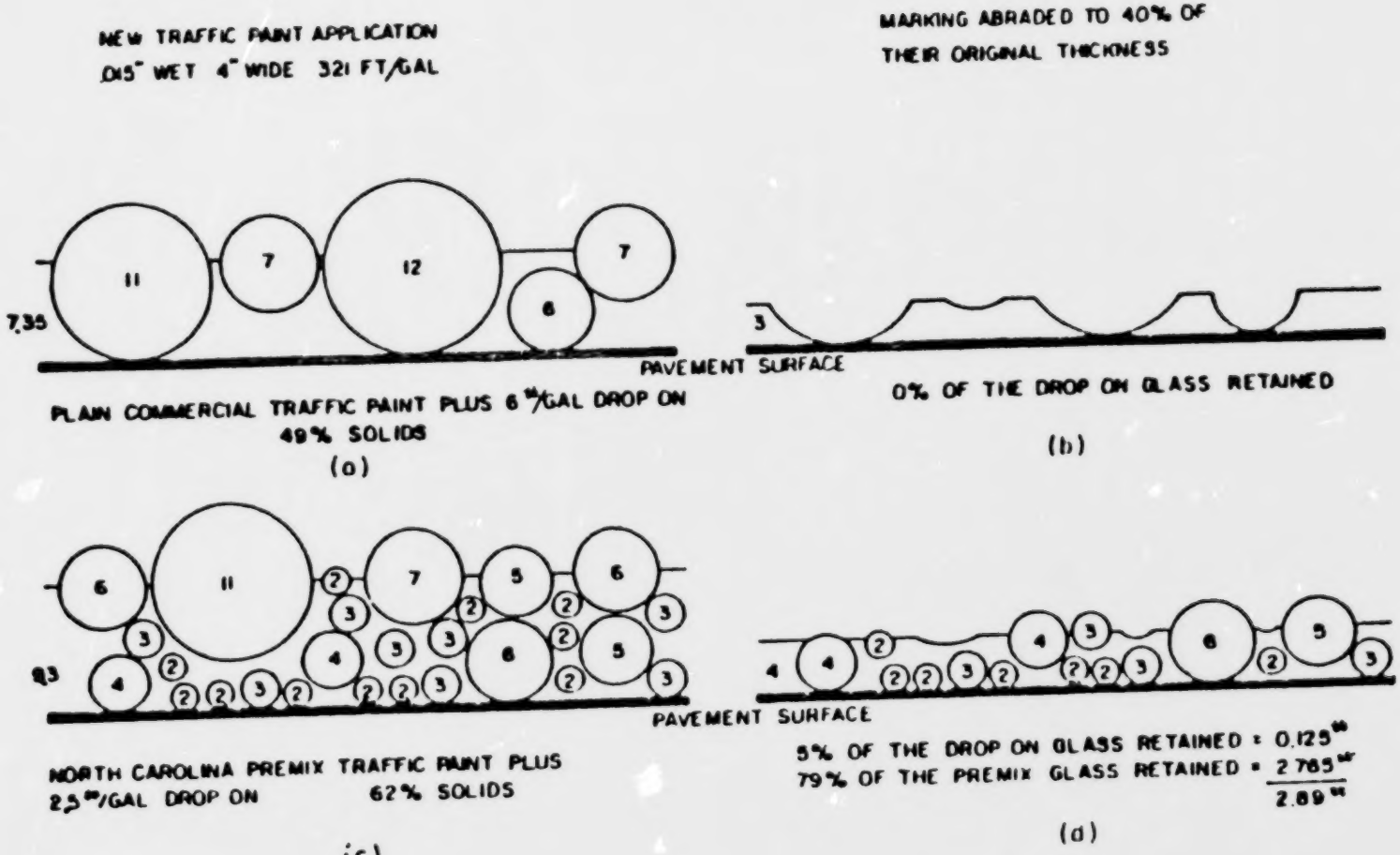


Figure 2: Glass Bead Retention

The refractive index varies between 1.50 and 1.90 depending upon the application and the agency which requires them. Beads that have a refractive index of 1.90 are approximately four times the cost of 1.50 beads and must be applied at a rate that is 1.8 times greater. Even though they have superior reflectivity, 1.90 beads are rarely used due to high cost [33].

A typical application rate of glass beads is 0.4 to 0.6 kg/L (4 to 6 lbs/gal). They can be premixed with the paint, dropped on later, or a combination of the two. According to Rhudy and Ritter [34], the premixed dual system increases the marking's durability and reflectivity. The only disadvantage of this system is its low initial night time reflectivity.

One of the largest problems with glass beads is the retention of them on the pavement surface. Many technical advancements have improved both the bead performance and the retroreflectivity measurement capabilities. Bead binder systems such as AC-04 silane coatings have been developed to increase the bead retention. Other moisture proof coatings are currently in use but do not perform as well as the silane coatings.

Glass beads are now widely used. They are very hard to replace as no other system seems to reflectorize the traffic markings quite as well. Polyester beads have been manufactured and tested. They have proven to be successful, but are slow to gain popularity. Until a better, cheaper substitute can be manufactured, glass beads will likely maintain a vital role in roadway delineation.

Within the Ontario Ministry of Transportation, a proposal was made to improve the retroreflectivity of glass beads in wet weather. The proposal was introduced in 1975 by D. Lazarow, but due to budget constraints during the 1978/79 fiscal year, the project was dropped [11]. The idea was to have fibres protrude from the surface of the pavement marking so that more light could be reflected during wet conditions. The fibres could be made of acrylic acetate, polyester, or nylon. When the roadway becomes wet, the fibres would protrude above the surface. The retroreflectivity of the glass beads must be measured occasionally. This is done with a reflectometer which emits a light and measures how much light is reflected back towards the driver.

Currently, the Ministry of Transportation of Ontario possesses a small, portable, in-house designed and constructed reflectometer. It is a reflectometer with a low resolving power

and a scale reading between 0 and 35. The newer and improved commercially built machines are scaled between 0 and approximately 350. All reflectometers have an illumination angle (incident light) in the 85 to 89° range, while the observation angle (reflected light) is approximately 1 or 2°. Not all reflectometers are easily portable. Some are very large or they are even incorporated into cars or trucks.

Pigments

Pigments are substances that impart colours to a variety of materials including paints. The yellow and white colours of road traffic markings are produced by the pigment contained in them. There are many types of pigments. Some of these have been labelled as environmental hazards and alternates have been developed for safe handling, for example lead pigments are considered toxic.

The degree of toxicity is determined by the degree of acid solubility tested by DIN/150 6713 [35]. The solubility of lead chromate is considered by the pigment manufacturing industry low enough to be environmentally safe. Very recently, efforts to further reduce the solubility led to the development of a chrome pigment "Krolor-LS" which is 10,000 fold less soluble than zinc chromate. Krolor-LS has been designed to provide maximum protection to the environment by putting a shell of glass (silica) around the pigment particle. This brings the soluble lead and chromium values down substantially to safer levels.

An alternative to toxic pigments are organic pigments currently in use in California.

Two organic yellow formulations were tested in Maryland, Nebraska, New Jersey, and Texas. A few problems were experienced with the settling and colour properties [36]. The ability to formulate an organic traffic paint that functions properly is entirely feasible. During the 1970's when many people were experimenting with organic pigments, the cost of these pigments was very high and availability, low.

In 1978 Niessner [36] reported laboratory and field test results from a FHWA sponsored study of 36 yellow traffic paints which were formulated with alternative pigments. He concluded that the performance of many organic pigments is superior to lead chromate.

In Maryland, a comparison test was undertaken involving road markings containing organic and non-organic pigments [37]. Alkyd and chlorinated rubber paints and

thermoplastics were tested in 1976. Overall, the performance of organic pigmented markings was superior. The colour change was superior and the bleeding was about the same. High temperature is a concern in the case of thermoplastics. However, non-organic lead chromate must be encapsulated in thermoplastics due to their high application temperature.

Most agencies that have or are studying organic pigment as an alternative to the presently used pigments believe that one day it will be possible to stripe the roads with organic pigments in the pavement markings. There are still a few obstacles to widespread use and new technology is being developed to overcome them. California is a leader in this field, with their work on organic pigments. Since the yellow paint, which contains toxic lead chromate, is the main environmental concern, it has been suggested that the role of yellow markings be greatly reduced or eliminated [14].

Solvents

Solvents are added to road traffic paints during production to make road striping fast, simple, and efficient. During striping they evaporate and the markings dry and solidify.

One of the most important factors in the application of road traffic markings is the dry time. The dry time is mainly a function of the solvent used in the paint formulation. Some typical dry times are listed in Table 3. Markings which have fast evaporating solvents are called non-coning. This means that warning cones do not need to be placed to keep motorists off the lines until they are dry. Presently non-coning paints are preferred due to their ease of application and the minimal interruption of traffic flow.

Worker safety is another factor that must be considered during the solvent selection. Most paint solvents are flammable and their vapours may be explosive. Almost all solvents have toxic effects and prolonged exposure can effect a worker's health. Absorption through the skin can also lead to health problems. Some of the symptoms are headaches, vertigo, vomiting, and even cancer. The safety of the solvent must be assessed and proper protection must be worn [38, 39].

It must be noted that safety and disposal methods are costly. This added cost comes into effect when a solvent is being chosen for a certain type of paint.

TABLE 3: PAINT SOLVENTS AND SOME OF THEIR PROPERTIES

SOLVENT	DRY TIME (seconds)	HEALTH* HAZARD	FLAMABILITY
Methylene Chloride	0.4	2	1
Acetone	0.8	1	3
Hexane	0.8	1	3
Benzol	1.2	?	?
Methyl Ethyl Keytone	1.5	1	3
Toulene	2.7	2	3
VM & P Naptha	3.5	?	3
Xylol	10.8	2	3
Turpentine	15.5	1	3
Mineral Spirits	33.0	?	?
Kerosene	325.0	0	2

References [3] and [39].

* NFPA (National Fire Protection Association) Rating 0->4, 0 being harmless, 4 being harmful (see [39])

3. IN-HOUSE TECHNOLOGY

3.1 General

The Ministry of Transportation's pavement marking technology at Downsview is primarily located at the Maintenance Operations Office, Equipment Engineering Office, Traffic Management and Engineering Office, Chemical Section, and the Research & Development Branch. Shared between these departments are the responsibilities for product evaluation, selection, standard specification, procurement, quality control, and field application.

Qualification testing of traffic paint samples was carried out annually during the early 1950's from June to December in order to select paints for purchase in January of the following year. In the late 1950's, the field test period was extended to one full year (June to June) in order to ensure that the paints would also be subjected to winter weather conditions. This resulted in the now practiced, two year test cycle. The procurement of the selected products is handled by the Purchasing Section through tender from designated suppliers. The supply quantities and shipping schedules are submitted by the Maintenance Operations Office based on projected requirements for each District.

Most of the Ministry's in-house technology pertains to the conventional alkyd based traffic paint. However, with the advent of novel, more durable pavement markings, trial evaluations and use of durable materials by special provision are carried out under the auspices of the Maintenance Operations Office, which is also the custodial office for pavement markings of the New Products Committee (NPC) as outlined by the Ministry Directive B29.

The material specification and procedure for conventional traffic paint evaluation, acceptance, and field application as well as trial evaluation and use of novel, more durable traffic markings are described in the following sections.

3.2 Material Specifications

The traffic paint specifications currently used in Ontario are for alkyd paint only, i.e.:

OPSS 1711-1: Material Specification for Non-Coning Traffic Paint

OPSS 1710-1: Material Specification for Coning and Non-Coning Traffic Paints

OPSS 1750: Traffic Paint Reflectioned Glass Beads

These are based on composition specifications and have evolved over several decades. They are related to the following:

Canadian General Standards Board (CGSB)

- 1-GP-74M – Paint, Traffic Alkyd
- 1-GP-149 – Paint, Traffic, Reflectorized, Alkyd, Yellow and White

U.S. Federal Government Specification

- TT-P-115F – Paint, Traffic (Highway, White and Yellow)
- TT-B-1325A – Beads (Glass Spheres) Retro-Reflective

These specifications, which are now a combination of composition and performance specifications, are used in Ontario and most U.S. States for purchase of traffic paint. The composition specification defines exactly how the paint will be formulated as well as the raw materials to be used. The contract for paint production is awarded to the lowest bidder, who is required to strictly comply with the specification.

Although the formulation has been designed and field tested to attain maximum performance, the quality of product appears to be difficult to control and enforce. Internal correspondence by R.A. Sterk [40] indicates some problems and confusion associated with changing and updating the composition type specifications.

Most recent specification improvements are in application related properties such as drying time, consistency, and paint tracking. However, the expertise and technology to formulate a more durable paint does not and cannot be expected to exist within the Ministry. The OPSS specifications don't attempt to define and specify the type and level of alkyd resin or detailed composition of the polymer used in the formulation for alkyd traffic paints. File notes [41] indicate attempts to characterize linseed and soya alkyd resins by Reichold.

Because of inadequate specification, product quality began to drop. Performance was not a requirement or responsibility of the supplier according to the specification. The procurement procedure allowed a few low bidders to dominate the market.

Faced with a declining product quality and increased need for durability due to higher traffic volumes, paint selection criteria in Ontario slowly began to shift toward performance

evaluation. The suppliers of paint who meet the test deck performance requirements were allowed to bid on supply contracts for the Province. Because no performance criteria or specification had been formalized, this procedure was awkward to implement and appears to favour the same few low bidders. This is because few suppliers were left who were interested in competing in a tendering process which allowed poor quality products and a low price structure to develop in Ontario.

In June 1987, the Maintenance Operations Office proposed the limited use of "superior products": those which showed over 90% retention in a 10 month period on the Ministry's test decks [42]. This approach is intended as a first step in the introducion of a performance specification. The long term objective is to develop a performance specification which will give the paint manufacturers a limited number of requirements which are necessary for the application of an acceptable line. The paint manufacturer is then required to exercise his expertise in formulating a paint which will perform satisfactorily as defined in a designated OPSS performance specification. Satisfactory performance must be defined in order that the "cost-per-meter-per-day-of-useful-life" can be calculated from the bid price.

A limited number of laboratory tests are needed for both the composition and performance specification methods for quality control of the product.

3.3 Product Evaluation and Acceptance

3.3.1 Laboratory Testing

The Chemical Laboratory at Downsview is equipped and capable to conduct all required specification testing for conventional alkyd paints. Samples are subjected to laboratory test for two main reasons:

1. To screen paint samples submitted for performance testing and verify compliance with specifications prior to inclusion in a test deck.
2. For routine quality control and assurance during the production season.

Once a manufacturer is supplying paint to the Ministry, the paint's composition must be checked periodically to ensure that it conforms to the exact composition of the bid sample. This process is intended to discourage the addition of alternate and/or inferior materials by the paint suppliers. Unfortunately, laboratory tests have not yet been developed to control every ingredient in the paint.

The main laboratory tests, routinely carried out by the Chemical Section on conventional alkyd paints, are listed in Figure 3 and summarized below:

A. **Mass/Litre** – Each production batch sample shall be within 0.05 kg/L of the value established on the test sample.
   * CGSB Method 2.1 of 1-GP-71.

B. **Viscosity (K.U.)** – The viscosity or "consistency" is performed with the Stormer Viscosimeter at a shearing rate of 100 revolutions per 30 seconds and temperatures of 7°C and 25°C.
   * CGSB Method 4.5 of 1-GP-71.

C. **No Pick-Up (minutes)** – No visible deposition of paint in a simulated passing over manoeuver indicates the no pick-up (no track) time.
   * ASTM D711.

D. **Hiding Power (m^2/L)** – The hiding power is based on the Pfund black and white cryptometer with a No. 3.5 wedge.
   * Described in Reference [43].

E. **Degree of Bleeding** – The bleeding characteristic (type of discolouration) on coal tar saturated felt is determined by comparative evaluation using pictorial reference standards.
   * ASTM D868 and D969.

F. **Rate of Settling** – The degree of pigment suspension and ease of remixing is determined on a scale from 10 to 0 following a description of paint condition after 5 days and 12 months.
   * ASTM D869.

G. **Fineness of Grind (Hegman)** – The minimum fineness of grind (or dispersion) should be 3.0 on the Hegman scale.
   * ASTM D1210.

FIGURE 3: Data Sheet

Ministry of Transportation and Communications
Ontario

TRAFFIC PAINT TEST RESULTS - QUALITY CONTROL

ENGINEERING MATERIALS OFFICE
CHEMICALS SECTION

MANUFACTURER _____ CODE NO. _____

SOURCE OF SAMPLE _____ COLOUR _____

LABORATORY NUMBER					REFERANCE SAMPLE
BATCH NUMBER					
DATE RECEIVED					
PHYSICAL TEST					
Mass per litre (kg)					
Consistency (K.U.) at 7°C					
at 25°C					
No pick-up time (min)					
Hiding power (m^2/L)					
Bleeding test					
Settling test (accel'd)					
Fineness of grind (Heg)					
Coarse particles (%)					
Retained # 60 mesh					
# 100 mesh					
Reflectance					
Water content					
Colour difference (NBS units)					
PAINT COMPOSITION					
% Pigment (by mass)					
% Vehicle solids (by mass)					
% Volatile (by mass)					
% Volatile (by volume)					
Veh. sol. / volatile ratio					
PIGMENT COMPOSITION					
% Insoluble					
% TiO_2					
% $CaCO_3$					
% PbO					
% Cr_2O_3					
% MgO					
VEHICLE COMPOSITION					
% Phthalic anhydride					
Infrared analysis					
SOLVENT COMPOSITION					

PH-CC-393 83-05

H. **Coarse Particles (%)** – The content of coarse particles is determined on sieves No. 60 and No. 100.
* ASTM D185.

I. **Reflectance (%)** – The directional reflectance (45° to 0°) is determined by means of a filter photometer conforming to the sensitivity of the average human eye (y-tristimulus filter).
* ASTM E97.

J. **Water Content (%)** – The water content is determined by distillation.
* CGSB Method 24.1 of 1-GP-71.

K. **Colour Difference (NB Smith)** – A Gardner Colour Difference Meter is used to determine the deviation of colour tone from the accepted standard.
* Gardner Instrument Test Manual.

L. **Pigment Content (%)** – An ordinary centrifuge method is used to determine the percentage of pigment.
* CGSB Method 21.1 of 1-GP-71.

M. **Vehicle Solids Content (%)** – is calculated from J and L.

N. **Volatile Contents (%)** – The volatile matter of pigmented paint is determined by evaporation at 105°C in an open dish.
* CGDB Method 17.1 of 1-GP-71.

O. **Pigment Analysis (% TiO_2, $CaCO_3$, PbO, CrO_3, MgO, Al_2O_3)** – The oxides are determined by appropriate ASTM procedure.

P. **Insolubles (%)** – The sample is extracted with a solvent mixture described by an in-house Ministry laboratory test method.

Q **Phthalic Anhydride (%)** – The phthalic anhydride content is determined gravimetrically by saponification and precipitation with alcoholic potassium hydroxide. * ASTM D1306.

R. **Heat Loss (%)** – The weight loss is determined upon heating to 900°C for white paint and to 550°C for yellow paint.

S. **Reflectorizing Glass Bead Testing** – The glass beads used in traffic paints will be tested for roundness (ASTM D1155), gradation (ASTM D1214), inspection and water resistance as described in OPSS 1750.

In addition to the above listed routine test methods, more specific testing can be performed if required. Often the laboratory tests are used to identify problems that are experienced in the field. A quick set of tests can identify compositional changes and thus help to identify and correct the problem. Most of the laboratory work is done in-house, but occasionally testing is commissioned to an outside agency.

A research project was undertaken in 1986 for the Ministry of Transportation [44]. Laboratory tests were done on 11 different paints (solvent and water based) to determine the general composition, physical properties, and relative performance under varied conditions. The purpose of these tests was to:

1. establish the critical parameters needed for designing paint application equipment;
2. compare the performance of water-based paints vs. solvent-based paints;
3. select the best performing paints from each category (water or solvent-based).

The best data was presented in a consultant's report, but no further action was taken.

As part of the quality assurance program, each District retains traffic paint samples from each batch of delivered product. Unless problems arise, every fifth batch (16 to 18,000 L) is tested partially and every 25th batch is tested completely by the Chemical Section. A partial quality control analysis includes physical tests and paint composition (see Figure 3). The complete analysis includes pigment, vehicle and solvent composition.

3.3.2 Field Testing

Since the early 1950's the Ministry has evaluated traffic paints by field performance testing in addition to the regular laboratory qualification test methods. The test results are primarily used for the selection and purchase of conventional traffic paints in Ontario. Here, like in most other jurisdictions, the proper specifying technique and performance assessment procedure have been a much debated issue. As a result, the material specification and product selection process have undergone frequent changes, giving performance testing more emphasis.

Recent accelerated performance field tests and some associated test method modifications have been described by R.Y. Fujii in February 1983 [45] and November 1984 [46]. Transverse test stripes are applied at the selected test site having a wet paint thickness of 16 to 18 mils (406 to 457 μm). The performance of the traffic paints on this test deck is monitored about every two months by the following tests:

a) Wear or Paint Remaining (%) - The wear of the paint stripes is determined by taking close-up photographs of the stripes and estimating the percentage of paint remaining in the area of greatest traffic wear (wheel path).

b) Beads Remaining (%) - The loss of beads in the wheel path is determined.

c) Reflectance Rating - The reflectance is measured by means of the reflectometer. The unpainted road surface is used as reference.

d) Appearance and Colour - The appearance of the test stripes is rated on a scale of 0 to 10 (0 is complete failure and 10 is perfect).

e) Overspray - Wet overspray and dribbling of the paints is rated from very slight, slight, fair to excessive.

In the fall of 1982, an accelerated performance test rig (merry-go-round) was set up at Downsview, north of parking lot "J" as a possible substitute for field performance testing [45, 46]. The initial experiments were repeated in August 1983. The project was abandoned because of equipment failure, softening of pavement in the summer heat, and poor

durability correlation in the two week test period. The duration of the test cycle was thought to be too short and climatic and site-specific conditions could not be simulated adequately.

The preferred and practical performance testing is at present a test deck on a high volume traffic roadway. Some key observations and concerns are summarized in the following:

Test Strip Applicator

Several different types of spray application units were used and tested in order to obtain uniformity of paint thickness, application speed, and simulation of hot, airless spray method [45, 47].

Test Site Selection

Important selection criteria are geographic location, road surface condition (including OFC and DFC) and traffic volume. While paints wear in the same order, they have been found to wear at different rates in different areas because of weather, salting, sanding, etc. Guidelines for test site location are given in ASTM D713.

Length of Performance Test

Preferably, the test is continued until failure occurs. Since the wear pattern of a line is not linear, the "useful service life" should not be calculated from predetermined test data using the formula found in ASTM D713 [48]. In any case, for Ontario, the test period should include the winter months [45].

Need for Revised Specifications

Revision of the existing specification to better reflect performance is needed. Also requested are modifications that will accommodate special requirements for the application equipment, e.g. consistency, shorter drying time, etc.

Field testing of novel, more durable pavement markings, e.g. thermoplastics, preformed tapes, etc. will be covered in Section 3.5.

3.3.3 Purchase by Tender

A request for quotation with a copy of the specification form No. 1711 attached is sent to prospective paint manufacturers whose test samples have passed Ministry laboratory and field testing criteria. The low bidder of each traffic paint lot will win the contract for the season's supply according to a specified delivery schedule for each of the eighteen Districts. Batch samples must be supplied to the Ministry and approval for each batch must be obtained prior to delivery. Continued or excessive failure to meet the specifications and/or composition of the approved sample may result in the termination of the contract.

The above practice has fostered low cost paint production, for example $1.51 per litre, but has at the same time lowered the quality of the paint and produced a bottom line bidding situation that most medium to large size paint manufacturers are not interested in. Maintenance Operations Office, as already described in Section 3.2.1, has taken steps to improve product quality and supply situations.

3.4 Field Application

Most purchased conventional traffic paint is applied by the Ministry's own zone-striping crews in each District with one exception: Kenora. The in-house technology with regard to field application is well established and advanced. A few comments on handling and storage of traffic paints as well as on the status of striping equipment will be given in the following sections.

3.4.1 Handling and Storage

Paint is shipped in clean, reusable, heavy gauge, open head drums with heavy ring and bolt closure to avoid spillage or damage when handling.

The 45 gallon drums meet C.T.C. Specification No. 17H. They are also furnished with 6 mil minimum plastic liner and cover sheet so that the opening will maintain an air-tight seal. To keep the inventory/storage at a minimum, delivery during the zone-striping season is in accordance with schedules provided by the Districts.

While specifications for traffic paint are written to insure against caking and excessive settling of the pigment, it is good practice to stir the paint to ensure complete remixing prior to use. If the product has to be held for an extended period of time, for example over the

winter, the drum should be stored upside down so that any settling or deposits will occur on the lid of the container.

A combined State study [49] by teams from Florida, Illinois, New Mexico, North Carolina, and FHWA has concluded that:

1. recycling of drums is economically not feasible (too many leakage problems);
2. larger drums (55 gal/208 L) are more economical;
3. bulk paint storage can offer savings (Illinois).

The bulk paint storage and handling concept has not been actively pursued in Ontario, but has been considered as part of a proposal for a high speed zone striper [50]. Another advancement worth considering is a computerized pavement marking management system, similar to the one introduced by Pennsylvania in 1984 [51]. Each District records daily material usage, lane miles painted, and manhours worked for each paint crew. From this information application and production rates can be calculated and maintained.

3.4.2 Striping Equipment

The Ministry designs, constructs, and services its own fleet of 17 zone stripers in order to maintain an average of 40,000 km of line markings per year. The lack of satisfactory lane marking equipment in the marketplace and the need for "hands-on" in-house expertise for equipment service led MTO to make rather than buy zone striping equipment. A study [52] carried out for the Equipment Engineering Office in 1986 concluded:

> "that MTC should continue to make their own stripers as opposed to the alternative buy decision. Their zone striper has very good qualities and measures up to any striper presented through this pavement marking study." (sic)

An earlier report [5] summarized advantages and disadvantages of owning equipment for applying durable pavement markings. To date, Ministry equipment is designed to apply only conventional, alkyd paints. Durable pavement markings are installed by suppliers or subcontractors. Several internal studies in 1980-82 have analyzed and critically reviewed the zone striping operation [53-57]. The key findings and concerns were:

- low production rates
- operator training and certification
- updating procedural guidelines
- paint quality

TABLE 4: MTO STRIPING FLEET DATA

	1977 Stripers Statistics	1986 Stripers Statistics
Number in Fleet	23	17
Make	own	own
Paint Capacity	540 gal. (US)	1500 lbs
Bead Capacity	1200 gal. (US)	4000 lbs.
Line Capability	3 anytime 2 colours	3 anytime 2 colours
Gross Vehicle Weight	35000 lbs.	50000 lbs.
Maximum Pressure	120 PSI	125 PSI
Maximum Cubic Feet (min)	160 CFM	185 CFM
Maximum Temperature	220°F	185°F
Paint Applicator System	airless	airless
Application System	10-12 mph	12-16 mph
Dry Thickness	9 mils wet	9 mils wet
Applied Temperature	130°-160°F	130°-160°F
Dry Time	40 seconds	40 seconds
Bead Application	air assisted	ais assisted
Applied Rate	7 lb./gal.	7 lb. gal.
Striper Cost	?	$133000 Can
Maintenance Costs	$8-10000 year	new

These reviews have kept the Ministry's fleet of zone stripers up-to-date. Table 4 shows a comparison of the Ministy's striping fleet data for 1977 with 1986.

Studies [50] are now underway to develop a high speed zone striper with anticipated operating speeds of between 15 to 40 mph (20 to 60 km/h). As many roads in the Province are unsuited for high speed operation, the striper must have speed flexibility. The main reasons for increasing the speed of the zone stripers are:

1. Minimizing traffic delay by operating the zone striper at speeds closer to that of the prevailing traffic.
2. Reducing operating cost.
3. Providing better crew safety.

A critical consideration is the drying time or wet-tracking of the paint. Normal wet-tracking times are two to six minutes with hot paint applied at 125 to 140°F (52 to 60°C). However, claims of 90 seconds have been made for fast drying paints, but only if applied at 180°F (82°C). Accelerating paint drying times may reduce the distance of wet paint left behind the striper, but will also reduce durability and bonding of the paint to the road surface.

The Equipment Engineering Office is currently studying the support of both a) speed and b) quality of the zone striping operation, i.e., the feasibility of self-aligning paint guns and an automatic on/off switch. The Amakos pump for applying an automatic constant spray film thickness is also under consideration [57, 58].

3.5 Trial Evaluation and Use of Durable Materials

Durable pavement marking materials are currently being evaluated to determine whether they could be cost effective alternatives to the present system. In order to determine this, several factors must be tested in a full scale field test section.

The key factors are:

1. durability
2. reflectivity
3. labour costs
4. marking costs
5. equipment costs
6. application procedures

During 1974, several tests took place and were documented by the Ministry. Different shades of paint were applied and tested to determine the best shade for traffic markings [60]. Vinyl traffic paint was also tested but extreme settling problems were not solved by the supplying company and, as a result, this type of paint was not recommended for use.

Extruded thermoplastics manufactured by Lafrentz, were first tested during the 1975 season [62]. These markings lasted 6 to 10 times longer than alkyd paint.

In August and September 1978, a test application of Nilaspray and Stamark traffic markings were laid [63]. Nilaspray is a spray thermoplastic while Stamark is a preformed tape. Both of these markings were placed at various locations along Highway 401 in the Metro Toronto area. Stamark tapes exhibited a good durability on concrete pavement in high density areas, lasting at least three years. When inlaid on bituminous pavement, the Stamark tapes lasted only about two years. The Nilaspray had a very poor durability when applied to concrete: it lasted only one year. On bituminous pavements, the marking's life was extended to between two and three years in high density traffic areas.

Romark polyester paint was evaluated in 1982. From the field test results, it was determined that polyester markings could out last alkyd paints by eight to ten times. In preparation for the application of the test markings, it was discovered that the equipment modifications were relatively easy and economical.

Also during 1982, acrylic cold-hardening plastics from Serval Industries were applied in three locations along Highway 7 near Metro Toronto. The districts involved were very impressed and they began planning another 20 installations for the 1983 painting season.

Two component epoxy was tested in 1983. Excessively long drying times were noted on cool surfaces. Although the edges of these markings had excellent reflectivity, the centre of them did not. This was caused by the glass beads being embedded too deeply in an epoxy film.

A large set of road marking materials were installed in 1983 by District 6. These markings were tested and the observations and results were documented in brief. 3M Stamark tapes

(5730, 5750) were laid on various locations including the collector lanes of Highway 401 from Highway 400 to Highway 409. These tapes had good visibility, good flexibility, and a high cost. Alkyd thermoplastic paint from Swarolite was documented as having a good visibility. These markings were laid 90 to 100 mils thick. Hydrocarbon thermoplastics were placed by Lafrentz on Highway 7 at Yonge Street and at Bayview Avenue. Good definition was noted as well as traffic discolouration. Finally, Epoflex from two companies (Ibis, Swarolite) was placed on Highways 401 and 403. Centrelines, edge lines, and intersection markings were installed. A poor colour was noticed and the very slow drying time presented many problems. Ibis placed epoxy paint at various locations surrounding Metro Toronto. The results were good overall. Colour retention and the wear patterns received fair ratings and there were cases where the markings became discoloured from traffic passing over top of them. A section of epoxy paint, that was mixed upon application, did not get recommended for use on open course concrete pavements.

A chlorinated rubber paint was applied during the 1984 painting season, in five Districts around Ontario. Considerable tracking was noted because the dry time was very long. 3M's Stamark 5730 pliant polymer tape was approved for use on illuminated highways this summer. Also approved for use on roads in Ontario were the hot spray thermoplastics by LaFrentz.

In October 1985, Ibis, LaFrentz, and Swarolite applied a variety of durable materials in test sections. There were two test sections, on Highway 401 at Weston Road and another at Dixie Road and Highway 401. From the files in the Chemical Section, it was possible to determine that Swarolite laid two thermoplastics and one two-component cold plastic. These test sections are still being monitored.

Mixtures of chlorinated rubber and modified alkyd paint were tested recently because straight chlorinated rubber had some drawbacks. It is too costly, needs plasticizers to dry fast, and becomes brittle upon drying. The evaluation continues and a report has not yet been issued.

4. TECHNOLOGY FROM OUTSIDE CONTACTS

This section deals with technology developed and/or used by Department of Transport agencies outside Ontario and by paint manufacturing companies. Contact was made by letter, telephone, and personal interviews or meetings. Additional information was also gathered from literature previously documented.

4.1 Other User Agencies

Canada

Each province was contacted by telephone and questioned about their pavement striping program. Most of the information gathered is summarized in Table 5. In addition, an exchange of information (specifications, technical reports, etc.) has been started between the Research and Development Branch and the provincial contacts.

There were many general trends noticed with each province's pavement marking program. Modified alkyd paint is the most popular type of road marking in Canada. Each province reported over 90% usage for the alkyd paint.

Since the review by McLean in 1986 [52], there are few developments or additions to the striping fleets in Canada. The truck mounted stripers are bought or made, depending on the provincial policy.

For the qualification of samples, all provinces mainly use compositional specifications. A few of the provinces combine performance specifications with their compositional set in order to approve products.

Durable materials are tested in most places, but do not comprise a large percentage of the total marking program. There are many types of products used in Canada, from epoxy paint to thermoplastics.

Contractors are not used in approximately one-half the provinces and are used very little in the remaining provinces. There is, however, an increase in the amount of road miles of markings planned for placement by contractors. In the provinces it is yet to be determined if hiring outside contractors is cost effective.

TABLE 5: PROVINCIAL PAVEMENT MARKING PROGRAMS

Province	Marking Type/ Usage	Markings Being Tested	Type of Specifications	Rating System In Field	Size of Striping Fleet	Amount of Contracted Work	Make, Buy or Modify Stripers
Alberta	1. Alkyd Paint - mostly 2. Thermoplastics - very 3. Preformed Tapes - little	1. All paints 2. Thermoplastics	Performance	N/A	7	Very little Only durables	Buy and slightly modify
British Columbia	1. Modified Alkyd - mostly 2. Thermoplastics - fair amt. 3. RPM's - few 4. Preformed Tapes - little	- Most new products	Performance and compostional	N/A	7	Very little	Buy and modify
Manitoba	1. Alkyd Paints - 98%	1. Preformed Tapes 2. Cold Plastics 3. All Paints	Performance	Subjective	3	None	Buy
New Brunswick	1. Alkyd Paints - 90% 2. Thermoplastics - 10%	1. Preformed Tapes	Compositional	Subjective	2	Less than 10%	Buy
Newfound-land	1. Alkyd Paint - 100%	1. Alkyd Paints 2. Thermoplastics 3. Preformed Tapes	Compositional	Subjective	2	None	Buy or modify old stripers
Nova Scotia	1. Alkyd Paint - 90% 2. Preformed Tape - 10%	- Chlorinated Rubber Paint	Compositional	Subjective	2	None	Buy
Ontario	1. Alkyd Paint 2. Preformed Tapes 3. Thermoplastics 4. Cold-plastics	- Most new products	Compositional	Subjective, reflectometer, % glass beads	17		Make
Prince Edward Island	1. Alkyd Paint - mostly 2. Preformed Tapes - little 3. Thermoplastics - little	None	Compositional	Subjective	1	Very little Only durables	Buy
Saskatche-wan	1. Modified Alkyd - 99% 2. Preformed Tapes - 1%	1. Cold Plastic 2. Long-life Paint	Performance and compositional	Subjective	5	None	Make
Quebec	1. Alkyd Paint - mostly	1. Preformed Tapes 2. Thermoplastics 3. Epoxy	Compositional	Reflectivity Appearance Durability	13	About $20,000/yr	Buy and modify

United States

The Federal Highway Administration (FHWA), mainly through its Traffic Control Systems Division, has provided a major initiative directed towards an improved pavement marking program. FHWA's funding and staff is involved in conducting field reviews/training and demonstration projects, research and development projects, establishment of National Testing Center and the sharing of technology.

Applying and maintaining pavement markings in the U.S. costs $390 million per year. The key areas of concern for this major activity, as viewed by FHWA, are: (a) material selection, (b) specifications, and (c) quality/quantity control [64]. The predominant material selection and procurement method used is based on compositional specifications. However, the number of States changing to performance specifications is increasing. The list of States using the performance approach include:

- California
- Delaware
- Florida
- Kentucky
- Maryland
- Michigan
- Wisconsin
- Ohio
- Oregon
- Pennsylvania
- South Carolina
- Virginia
- West Virginia

Much of the pioneering work in the development of new technology has been carried out by the States of Michigan, New York, Ohio, and Pennsylvania (see Section 2). Many research and development projects have also been initiated and supported by FHWA.

An overview of current practices for a selected group of states is summarized in Table 6. Note that there is a trend towards increased acceptance of the more durable pavement marking systems such as two-component polyesters and epoxy materials. There are now over 10 suppliers of preformed tape, while a few years back there was only one, 3M.

There is an increased interest in testing retroreflective properties of pavement markings in the U.S. This trend is most likely a result of the development of performance

TABLE 6: PAVEMENT MARKING PRACTICES IN THE U.S.A.

State	Type of Specification	Use of Test Decks	Type of Materials Used Predominant	Other	No. of State Owned Stripers	Amount of Contract Work	Total Cost of Program (M$)
Illinois	Composition	Weatherometer	Chlorinated rubber paint	Thermoplastics Preformed Epoxy	26	All durables	3
Indiana	Composition	Test deck discont. 10 years ago	Alkyd, regular and fast dry	Thermoplastics Preformed	16- 1 for thermoplastics	$70-100,000	3
Michigan	Performance	Yes, for AC and PCC	Alkyd, fast dry	Polyester Preformed	6	All durables	4.7
Minnesota	Composition	Discont. test deck	Alkyd, fast dry (3 mins)	Chlorinated rubber epoxy (others)	12	All durables	4
New York	Composition	Yes	Alkyd	Thermoplastics Epoxy, Polyester Preformed	21	All durables	
Ohio	Performance	Yes	Alkyd, fast dry Polyester	Epoxy Thermoplastics	12	6.5 (80%)	8.5
Pennsylvania	Performance	Yes	Alkyd		15	Very little	11.12
Wisconsin	Performance	Yes, every 3 years	Alkyk (hot)	Epoxy Thermoplastics Preformed	9	All durables	1.5

specifications and an interest in several European methods of pavement marking material selection, for example in France, United Kingdom, and Germany.

France

More than 25 years ago, the French Government developed a system for approving pavement marking materials which is now known as the *Homologation System* [64, 65]. The procedure is administered by SETRA (Services d'Etudes Techniques des Routes et Antoroutes) and LCPC (Laboratoire Central des Ponts et Chaussees). The principle of the system is that the supplier is free to put forward his own formulation with whatever materials he wishes, as long as the pavement markings will meet the performance standards. The lynch pin of this system is the road service test. The four major criteria for assessment are:

- durability (wear)
- night time visibility (retroreflection)
- day time visibility (colour)
- skid resistance.

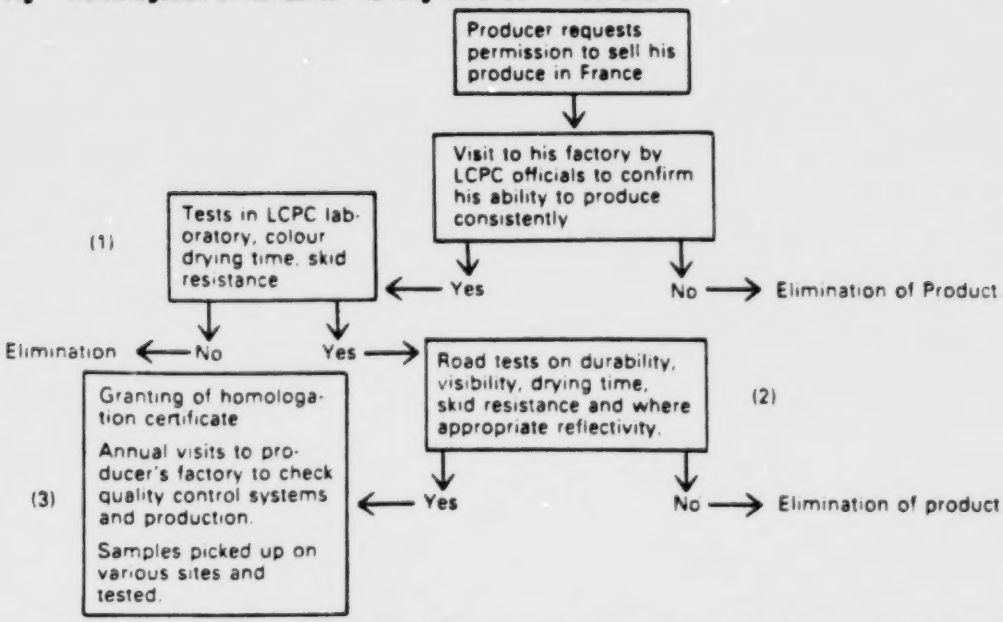
The procedure by which the LCPC evaluates each product submitted for homologation is depicted in Figure 4. When homologation is granted, the product is homologated with a service life of 12 months, 18 months, etc. The system is used for both conventional paints and thermoplastics.

It may be interesting to note that great care is taken to simulate actual field conditions for test deck application. For instance, in order to attain "real" field conditions for spraying, an enlarged shoulder along the test deck is used to allow the striper to gain actual marking speeds before spraying the transverse test stripes.

United Kingdom

The British Standard Institution (BSI) uses the "Kitemark" licensing scheme to improve and maintain high quality pavement markings [66]. There are some similarities to the French homologation system. The license to use the Kitemark in connection with a pavement marking material is granted when the manufacturer has demonstrated that he can consistently produce the required standard specifications.

Fig 4 **Homologation of Horizontal Marking Materials — Flow Chart.**


Producer requests permission to sell his produce in France
Visit to his factory by LCPC officials to confirm his ability to produce consistently
(1)
Tests in LCPC laboratory, colour drying time, skid resistance
Yes
No
Elimination of Product
Elimination
No
Yes
Road tests on durability, visibility, drying time, skid resistance and where appropriate reflectivity.
(2)
(3)
Granting of homologation certificate
Annual visits to producer's factory to check quality control systems and production.
Samples picked up on various sites and tested.
Yes
No
Elimination of product

(1) The aim is to minimise the chances of applying on the test site products which are obviously unsuitable.

(2) The application for the road tests is carried out by the producer's own employees with a marking machine. All aspects of application: weather, viscosity, dosage, drying time ... etc are noted by the Administration. For the dosages these are measured before and after the line application by test plates placed in the path of the machine. No beads are applied on the plates after the line and thus one has "dry" dosage with and without beads.

(3) Results after 12 months → FAIL → no homologation

↓

PASS → provisional homologation certificate for 12 months

Results after 18, 24, 30 months etc — FAIL → a definitive homologation valid for 4 years and showing the product's lifetime: 12 18, 24 months etc.

↓

continue to PASS provisional homologation certificate for 18, 24, 30 months.

The Kitemark scheme is used for both conventional paints and thermoplastics which relate to the specifications BS-6044 and BS-3262 respectively. The standard for conventional paints (i.e. BS-6044) has, since it was first published in 1960, undergone a change from a recipe specification to a performance specification.

A major acceptance requirement is – like in the homologation system – satisfactory performance on the test deck. However, there is no accepted technique or standard for night time visibility, whereas in France, the reflectometer is accepted.

One important advantage of the British Standard scheme is the recognition of different climates. Physical properties such as the softening point of thermoplastics may be changed if the climate is unsuitable. This is not possible with the French homologation scheme because markings are only tested in one climatic zone and hence may only be acceptable in that one area.

Germany

West Germany operates a product certification system for quality protection of road markings with major emphasis on day time and night time visibility. The certification concept is similar to the systems used in the United Kingdom and France.

The standards, test methods, and procedure regulations are administered by the Federal Institute for Road and Highway Administration (BASt). Details of the certification procedure are described in the *Handbook for Marking of Roads (HMS)* and the *Additional Technical Specifications and Guidelines for Markings on Roads (ZTV-M84)* [67, 68].

Some of the more interesting features include the following:

- Correlation of material selection to ADT and type or position of the marking on the road.
- Detailed description of monitoring the application of marking materials, e.g. surveying causes of irregularities.
- Self-conducted quality testing, i.e., tests conducted by contractor.

4.2 Pavement Marking Material Suppliers

Contact with suppliers and manufacturers has been in the form of interviews, telephone conversations, and correspondence. The response was initially slow. The reasons given for thier reluctantance include the following:

a) Major paint manufacturers lost interest because production by recipe for low cost favours the small manufacturer with low overhead.

b) Alkyd traffic paint as defined by the Ministy is considered a low margin commodity not appropriate for the kind of research and development expenditure necessary to improve paint quality and competition.

c) The acceptance procedure and practices in Ontario are poorly defined, have no feed-back on performance data, are lengthy (two year turn around), and unpredictable.

d) The potential volume is large and may upset manufacturing operations of other high profit margin products. The supplier is therefore exposed to a high risk factor when bidding for traffic paint.

Contacts with Canadian suppliers say that most product development (with a few exceptions such as SICO Inc. and Niagara Paint and Chemical Co. Ltd.) is done outside Canada at the parent company. Therefore, the local sales representative aren't familiar with new developments unless they request information from the parent company's experts. The following summaries are based on information provided by the suppliers.

BAPCO

The BAPCO company is in partnership with C-I-L Inc. and The Sherwin-Williams Co. and uses their trade marks and brands under license. This company supplies traffic paint with the following specifications: Federal Government IGP74M and MTC 1710 and 1711.

DALNOR Canada

DALNOR does not manufacture but is marketing Porter Paints Co. products, whose head-quarters are in Louisville, Kentucky.

DeSoto Coatings Ltd.

DeSoto has submitted test samples of alkyd traffic paint.

Durabond

Durabond has submitted a test sample in 1986.

Glidden Co.

Glidden has submitted an alkyd based traffic paint for road service testing. The company would be interested if the Ministry product selection system is modified to recognize performance quality. Glidden promotes a two-component polyester system which was developed by the Glidden Research and Development Division in Cleveland, Ohio. States using the system include Pennsylvania, Minnesota, Ohio, and Michigan.

In the summer of 1987, the Toronto Glidden laboratory examined two samples of Ministry alkyd traffic paint . The intent was to predict performance from chemical analysis. This proved to be difficult. A correlation between higher performance levels for paints with a higher resin to solids and a higher non-volatile to vehicle ratio could not be established.

Ibis/Prismo

Ibis Products Ltd. is a Canadian paint manufacturer who is licensed to produce and market Prismo Safety Corporation's pavement marking materials. Ibis is a major supplier to the Ministry. The available products from Ibis are:

Conventional Traffic Paint

- regular white and yellow
- coning and non-coning white and yellow
- Niteline II white and yellow
- Lifeguard II white and yellow

Permamark

- two-component, cold hardening plastic, white and yellow

Tape

- high reflective marking tape

Thermoplastic

- Ibis supplies materials and striping equipment.

International Paints

International produces industrial paints world wide and are known for marine coatings. The main research and development facilities are in the U.S.A. (New York, Texas) and England. International has, in the past, submitted traffic paints for testing by the Ministry. Recently Teknos-Maalit Oy, a Finnish licensee of International, formulated a two-component acrylic pavement marking for use in cold climates. The Ministry received an invitation to witness a field demonstration in Finland.

LaFrentz

LaFrentz Road Services Ltd. has offices in Edmonton and Oakville and has been producing plastic pavement markings in Canada since 1975. The products which are installed by LaFrentz include:

- surface sprayed thermoplastic, 300 Series (Nila, spray, old designation),
- surface-laid or in-laid, extruded thermoplastic, 300 Series (Nilaplast, old designation),
- two-component, solvent free, cold curing plastics, 400 Series,
- profiled (formed on site road markings, hydrocarbon based plastics), and
- Tarkett Verynyl preformed tape (discontinued).

LaFrentz has issued specifications for both the 300 Series and the 400 Series [69].

3M Canada Ltd.

The Safety and Security Systems Division of 3M has been pioneering the development of preformed pavement markings in their research centre in St. Paul, Minnesota. The two main brand names for 3M tapes are Stamark and Scotch-Lane with a pliant polymer and metal foil respectively. Different designs and grades are available for specific applications:

- Series 5730* for high volume roads
- Series 5750 for dark, rural roads
- Series 5710 for temporary use, removable
- Series 5160 for temporary use, non-removable
- Series 350 for improved visibility by raised diamond pattern
- Black-out tape for covering existing stripes (under development)

* Approved by the Ministry

An advantage of marking tapes is that they can be used soon after construction [70], however the lay-down equipment is not fully developed and automated. In Ontario, 3M has

two approved installers: Roller Craft, Etobicoke and Niagara Pavement Marking, Mississauga.

3M also developed a quick-dry, liquid striping compound with the brand name "Greene Lite". This compound, it is interesting to note, has since been withdrawn from the market.

Mark-All Services

Mark-All offers installation services. They are laying Permamark (TCHP) which is produced by Ibis and are developing equipment to apply this type of material (two-component, cold hardening plastic) automatically.

Niagara Paint

Niagara, a Canadian based manufacturer, has been supplying the Ministry for over 35 years with alkyd traffic paint.

SICO Inc.

SICO has submitted test samples for road performance testing and has expressed an interest in formulating improved, more durable products. Five drums of their paint were laid by the Burlington District on Dundas Highway in the summer of 1987 for future evaluation.

Valspar Inc.

Valspar sees the traffic paints currently in use in Ontario as a low margin commodity, not attractive to most paint manufacturers. The Ministry procedure for approval is thought of as lengthy and available only occasionally (twice in the last five years). They would be interested in a new approach directed to development of improved and new products. Valspar's research and development centre is in Minneapolis. Their current product line includes:

- modified alkyd paint
- chlorinated rubber paint
- polyester coatings

Like SICO, Valspar supplied a more "durable alkyd paint" for a trial in the Burlington District on Dundas Highway in the summer of 1987.

5. CRITICAL ASSESSMENT OF EXISTING TECHNOLOGY AND PRACTICES

5.1 General

Having reviewed the existing pavement marking technology and practices as reported in sections 2, 3 and 4 (literature search, in-house technology, technology from outside contacts), it is now possible to make a critical assessment with respect to:

a) status of available technologies,

b) performance quality of materials,

c) application requirements and considerations, and

d) economic considerations.

Subsequent assessment conforms to the evaluation criteria and priorities listed in Table 7. This checklist has been discussed with the client branches and consensus was obtained for the given priority rating. The underlying objective here is to develop an action plan based on this critical assessment of current pavement marking technologies and practices.

5.2 Status of Available Technologies

Since the original development of oil based traffic paints during the 1920's, pavement marking technology has advanced significantly. Developments have occured not only in the methods of application and performance quality, but also in the variety and durability of available base materials.

The conventional alkyd/oil based traffic paint is still the most widely used pavement marking material in spite of the emergence of novel materials with much superior durability. The technology is proven and established. The Ministry has kept up with any technological improvements, in particular in the area of field application and application equipment development. However, there have been difficulties in updating the existing specifications and hence monitoring and attaining the desired performance. Although the Ministry has in the past attempted new formulations of modified alkyd paints, mostly in the early stages of their development, the newly available technology has not yet been exploited.

TABLE 7: CRITICAL ASSESSMENT
(check list)

Evaluation Criteria	Order of Significance	Priority Rating*
Performance Quality	1	
- visibility/reflectivity		10
- durability		9
- adhesion (OPC, DFC, PCC)		9
- environmental safe/acceptable		5
- skid resistance		3
Economics	2	
- material cost		
- equipment cost		
- labour cost		
- other costs (traffic, safety/congestion)		
Application	3	
- versability		7
- drying time		10
- traffic considerations		8
- environmental factors		8
- complexity of application		10
- speed of application		10
- handling/storage		8
Technology Status	4	
- emerging		3
- pacing		5
- developing		8
- proven		10

* 10 for highest priority

Besides the modified, improved alkyd paints, alternate traffic paints, (i.e. solvent based paints) which can be applied with conventional stripers, have been developed. The technology for formulation and application of chlorinated rubber, latex, and epoxy based traffic paints has improved sufficiently over the past decade for highway authorities to specify their use, e.g. Missouri uses a fast dry chlorinated rubber traffic paint state-wide and California uses latex. Motivated by environmental considerations, good progress has been made with the development of lead free and water-based traffic paint formulations.

A variety of thermoplastic and also preformed plastic (tapes) pavement marking materials have been widely accepted. These alternatives to conventional traffic paints have been under study for over twenty years. The growing popularity is mostly due to the readiness for immediate use (tapes), superior durability, and long term economic benefit. Suggested procedures and guidelines for installation are available and FHWA [1] has developed a model specification for the purchase of both the thermoplastic and preformed plastic pavement marking materials.

The Ministry accepts manufacturers specifications for the following approved (approval in progress) products:

a) cold plastic	- Mark-All Services Inc.
	- LaFrentz Road Services Ltd.
b) thermoplastic	- LaFrentz Road Services Ltd.
c) polymer tape	- 3M, 5730 Staymark.

In summary, the technology for thermoplastic and preformed pavement marking materials is well established. However, new and improved formulations and materials are still being added. The application technology is still being refined and the availability of installation equipment is limited.

Two-part field-reacted pavement markings have been actively studied since the early 1970's. Because of the complexity of application, the technology has not yet matured. The main complicating factors are the monitoring and control of a chemical reaction under field conditions and the handling of dangerous chemicals, for example, methyl ethyl

ketone peroxide. The technology is limited to a few manufacturers, i.e., two-part epoxy developed by H.B. Fuller Co. and polyester by Glidden Paint Co.

Improvements in field application technology in recent years has resulted in superior field performance of two-component 100% solid epoxy or ester. User agencies such as Minnesota, Illinois, Michigan, and Wisconsin are encouraged by the development and see significant potential for the product. The application equipment is not yet readily available. Conventional stripers are being retrofitted to handle two-component pavement markings. The trade-offs for adopting this superior product are a higher complexity of the system, more sophisticated equipment, training and specialization, (e.g. handling of chemicals) of the pavement marking crew.

5.3 Performance Quality

To fulfil their function in providing for safety and order in traffic, pavement marking materials must perform well. The key performance requirements reviewed here are:

1. Visibility/retroreflectivity Sufficiently recognizable during day and night time.
2. Durability Sufficiently wear and weather resistant.
3. Adhesion Sticks well to base.
4. Environment protection Not containing substances infringing on environmental laws.
5. Skid resistance

Conventional alkyd based traffic paints probably exceed all other pavement marking materials in terms of roadway miles, but have some shortcomings in performance quality. The main concerns are poor wet-night visibility, shortest life, and contribution to air pollution from petroleum based solvents and lead chromate pigments. Moderate improvements in durability have been obtained with chlorinated rubber and epoxy based traffic paints and water-based paints are safer environmentally.

The real improvement in performance, especially with regard to durability, came with the advent of novel (thermoplastic, preformed or field-reacted) polymeric materials. All showed excellent durability, lasting 5 to 10 times longer than conventional traffic paints. Thermoplastics show the best wet-night visibility and retention of glass beads.

There is, however, some concern about adhesion. Thermoplastics and field-reacted polyesters adhere poorly to PCC surfaces especially in northern climates. Field-reacted epoxy exhibits poor adhesion to asphalt pavements. Adhesion in general is more sensitive to the installation conditions and procedure. Special provisions for adhesion may be required such as cleaning and drying the pavement surface and/or applying at the appropriate temperature, and compatibility with old painted surfaces. For example, preformed tapes may not adhere well late in the season, foil performs poorly on coarse textured pavement, and epoxy cannot be applied upon surfaces with conventional traffic paint.

In general, it has been demonstrated that the performance quality is also a function of complexity of the technology used. This is especially true for field-reacted systems where, for instance, the dosage of accelerator catalyst will affect the ultimate performance. Limiting factors related to application (e.g. drying and curing time) rather than materials and their impact on performance quality will be discussed in subsequent sections.

Environmental aspects have not, to date, played a significant role in the use of traffic paints in Ontario, because the quantities of hydro–carbon solvent (1.6 million L/yr.) used are low when considered as a percentage of Ontario's total area. The lead containing yellow pigments (about 250,000 kg of lead chromate per painting season) are assumed safe based on the low solubility of the lead chromates [35]. The banning of hydrocarbon solvents and lead pigments, which has occurred in several US States (e.g. California) has not yet been considered for Ontario [3]. Water-based (latex) paints have been greatly improved and should be considered. Furthermore, lead-free, yellow pigments are now available and could be used in Ontario.

All pavement markings cause a significant reduction in skid resistance (typically from SN 48 to 34). The resulting differential friction can create a hazard primarily for single-track vehicles (motorcycles). Lane delineation does not normally present a hazard for drivers of four-wheeled vehicles, even when the skid resistance of the marking material is very low. According to Anderson et al [71], the lowest levels of skid resistance are exhibited by hot extruded thermoplastic, chlorinated rubber paints, and polished beaded surfaces.

In cases of extremely low skid resistance, application to large areas, such as gores, legends, and stop bars should be avoided whenever possible. In general, the potential safety hazard presented by pavement markings should be weighed against the safety benefits provided by the marking.

5.4 Application Requirements

How readily a pavement marking can be used or applied is, next to performance quality and cost, the most significant consideration in the evaluation and selection of pavement marking materials. Factors that determine the field application of pavement markings are varied, numerous, and often interlinked. The more significant ones are as follows:

1. complexity of pavement marking system;
2. speed of installation;
3. drying/curing time;
4. traffic control considerations;
5. environmental/safety aspects;
6. handling/storage procedures; and
7. versatility of use.

For conventional alkyd paints, a relatively simple one-component system is used. Proper equipment, expertise, and trained crews are available in-house and in the private sector. The speed of installation has increased steadily, mostly through automation. An improvement of application rate from 20 km/hr to 60 km/hr [50] may be possible, but is limited by the slow drying of the paint. Higher rates of solvent evaporation cannot produce a uniform and durable film. Therefore, any gain in speed of application is lost in durability and "useful" service life, giving rise to more frequent paint applications and hence even higher application speeds.

The "no pick-up" time (ASTM D7711) or the "no tracking" time (the older version) simulating the passing of a passenger car (OPSS 1710 and 1711), will only rarely be as low as one minute which is the current Ministry maximum for non-coning traffic paints. Average drying times for paints tested by the Ministry in 1986 range from two to six minutes. Substantial improvement cannot be expected from conventional traffic paints. However, fast drying times have been claimed for several field-reacted traffic markings that also show promising durability, for example, two-part epoxy. Such claims will

have to be tested and verified. The application technology will almost certainly be more complex.

Traffic control considerations are directly linked to installation speed. Because of high cost and user inconvenience, coning should be avoided. Both from the safety and cost point of view, traffic control requirements should be related to site-specific parameters such as traffic density, speed, and volume. For example, a 20 minute drying time on Highway 401 in Toronto would not be acceptable except for special situations such as during new construction. Some installation procedures will require lane closure such as inlaid thermoplastic or preformed tape which gives excellent durability and resistance to snow plowing.

Environmental and safety aspects include the use of MEK solvent for chlorinated rubber paint, the use of strong chemicals, such as MEKP catalyst (peroxide), and high installation temperatures, e.g. 232°C (450°F) for thermoplastics. All the above potential problems avoided through adequate crew training, safety procedures, and equipment. These will add to the cost of the installation.

Some of the newer pavement marking materials are not as versatile as conventional traffic paint. Typical examples are:

- two-component polyesters which adhere poorly to PCC surfaces and require a two-week wait before being applied to new asphalt pavement surfaces;
- thermoplastics which adhere poorly to PCC surfaces in northern climates; and
- preformed tapes which adhere poorly in late season installations and on coarse textured surfaces.

The versatility of pavement markings may also be viewed in terms of special provisions for handling, shipping, storage, striping equipment, etc. For example, a latex paint may not be stored outside during the winter months.

5.5 Economic Considerations

Besides improvements of performance qualities to acceptable safety standards, economic considerations are the most important evaluation criteria for pavement markings. A value engineering study should lead to optimization and eventually to overall cost reduction. It

is, however, important to note that potential benefits are not necessarily direct cash savings to an agency like the Ministry of Transportation. Cost benefits are also realized in higher levels of service and increased productivity for the same public dollar.

Historically, the best value for the public dollar was determined by the tendering of traffic paints according to a locally established compositional specification. The user agency declares exactly how the paint shall be formulated based on local conditions, available raw materials, and field experience. This approach is no longer adequate because of the many different pavement marking materials and technologies available as well as increased performance requirements and applications.

Several cost analysis techniques, including some standard methods, have been described in the literature, for example:

- ASTM D713, *Practice for Conducting Road Service Tests on Fluid Traffic Marking Materials.*
- ITE (Tentative) Standard, *A Model Performance Specification for the Purchase of Pavement Marking Paints.*
- Roadway Delineation Practices Handbook [1], Appendix F, *Cost Analysis.*
- Value Engineering Study, Traffic Striping [72], Appendix B VI, *Evaluating and Computing Performance Ratings.*
- Determination of Life-Cycle Cost of Pavement Marking Materials [73].
- Pavement Marking Practices Report [64], Section 1.24, *Method Used by Virginia Department of Transportation.*

The three major components required for a cost benefit analysis are:

1. Selection of appropriate standards and materials for the specific applications.
2. Establishment of in-place cost of each material.
3. Determination of "useful" service life.

A universal formula or method of analysis is most likely not possible because:

a) the required input data is a function of site-specific considerations that do not lend themselves to quantification, for example, safety;

b) the rational selection of the most cost-effective marking material for a particular location may be insensitive to the interest rates that an agency might use in life-cycle cost determinations; and
c) performance can only be predicted using a wide sampling.

In fact, no model is a totally objective and quantitative method for selecting marking materials on the basis of cost. Hence, there is a need for the Ministry to develop its own method of pavement marking selections which will take into account Ontario-specific factors such as safety, environment, climate, and the like, as well as economic considerations.

5.6 Summary of Assessment

A status review of available technologies has shown that:

a) conventional traffic paint technology has been updated, and
b) new pavement marking materials are available.

In both instances, implementation in Ontario would result in a higher performance level of the pavement marking program. There is a genuine need for updating traffic paint specifications and improving product selection procedures.

The advantages and disadvantages of better quality materials and application requirements are summarized in Table 8 and are adopted from New York's experience [4]. Since the information has been collected, pavement marking improvements, especially in the quality of latex paints and the application of field-reacted materials, have been made. However, New York's findings are still essentially valid and can be applied to Ontario. A performance oriented pavement marking material selection procedure, which is tailored to Ontario's requirements, should be developed.

TABLE 8: ADVANTAGES AND DISADVANTAGES OF PAVEMENT MARKING MATERIALS

Material	Advantages	Disadvantages
TRAFFIC PAINTS		
Modified Alkyd	Lowest initial cost Good dry-night visibility Well established technology One component Short dry time available Relatively safe handling Good equipment availability	Shortest life Poor wet-night visibility Year-round delineation not always possible Consumes petroleum distillate, contributes to air pollution
Chlorinated Rubber	Low initial cost Good dry-night visibility Well established technology One-component Relatively safe handling Good equipment availability Better durability than alkyd	Poor wet-night visibility Year-round delineation not always possible Consumes petroleum distillate, contributes to air pollution Strong-smelling MEK solvent Long dry times (3 minutes at best)
Latex (water-based)	Low initial cost Good dry-night visibility One-component Safe handling Good equipment availability Does not use petroleum solvent	Poor wet-night visibility Year-round delineation not always possible Limited field experience Susceptible to rain damage during curing
Epoxy	Most durable paint Good dry-night visibility Relatively safe handling Good equipment availability External mixing ensures proper proportions	Limited field experience Uses strong-smelling MEK solvent Long dry time (2 minutes at best) Consumes petroleum distillate, contributes to air pollution
THERMOPLASTICS		
Alkyd and Hydrocarbon	Excellent durability Relatively safe materials Simple handcart for installation Good night visibility Wet-night visibility better than paint	Higher cost than most materials Safety concerns (high installation temperature) Adheres poorly to concrete in northern climates Installation must be closely controlled
Epoflex	Moderate cost Generic formulation Use spary equipment Fastest drying time (15 sec) Low temperature application Good night visibility 100% solids (no evaporation loss) Good durability on asphalt and concrete	Limited successful experience High installation temperature Drop-on bead timing critical
PREFORMED TAPES		
Plastic	Excellent durability Installation needs little of no equipment No safety hazard (no heat or chemicals) Small areas easily repaired Inland installation for snowplow resistance	Highest first-cost Variable night visibility Late-season installations may not adhere well Limited supplier competition
Foil	Good durability Installation requires little No safety hazard Small areas easily repaired Good dry-night visibility	High first-cost Late-season installations may not adhere well Performs poorly on coarse-textured pavement Limited supplier competition
FIELD-REACTED MATERIALS		
Epoxy	Excellent adhesion on concrete and asphalt Good durability Excellent night visibility Can be applied on damp pavement Safe to handle 100% solids (no evaporation loss) Moderate first-cost	Specialized, expensive installation equipment Mixing and proportioning of two components critical, difficult to check Slow no-track (2 minutes at best) pavement
Polyester	Good durability Low cost Installed with modified paint equipment Applies over existing paint Good supplier contractor competition 100% solids (no evaporation loss)	MEKP hardener requires careful handling, special tanks and lines Two-week cure required before striping new asphalt pavement Slowest cur time (10-15 minutes)

6. CONCLUSIONS

A review of pavement markings and a critical assessment of existing technology and practices has been completed. Ideas and an approach for improving currently used materials and application methods have been given. The key observations and conclusions are summarized in the following:

1. Improved pavement markings which could be exploited by the Ministry have been developed by the private sector.

2. In order to raise the performance level of the current traffic paint, Ontario's compositional pavement marking specifications should be replaced by performance specifications.

3. The material selection and tendering procedure must involve product performance and useful service life.

4. A cost benefit analysis model tailored to Ontario's situation and requirements should be developed.

5. Emphasis must be placed on monitoring field application quality and field performance by qualified, trained inspectors.

6. A pavement marking management system should be initiated featuring a data log of items such as material usage, lane miles painted, manhours expended, performance rating. It should include a data reduction system to assist product selection and budgeting.

7. RECOMMENDATIONS AND PROPOSED ACTION PLAN

7.1 Overview

The recommendations are presented in the form of an action plan proposed to improve existing materials and procedures. Presented here are the five main problem areas discussed in the preceding critical assessment of existing technologies and practices and are also summarized in Table 9. This proposed action plan is intended for the review and consideration of the Highway Operation and Maintenance Division. If approved, this action plan will be used for the development of specific project proposals.

Appropriate action points for each of the identified problem areas are described in more detail in the following sections.

7.2 Quality of Conventional Paints

The most serious quality problem of conventional paints now used in Ontario is poor durability, or short service life. Additional problems include poor wet and nighttime visibility, drying time limitations, and field application.

The most direct action to be considered for immediate improvement is to switch from compositional specifications to performance specifications. This is to say that most specifications related to application and handling, e.g. consistency, bleeding, settling, etc., remain part of the specification. Furthermore, compositional requirements (e.g. TiO_2%) are replaced by road service test specifications, in particular day and night time visibility, durability, no-track time, and skid resistance. Lifting the compositional constraints will give the paint manufacturer more freedom to formulate alternative and improved paints. However, once road tested and approved, the paint formulation must be guaranteed by the supplier with respect to composition and performance.

In order to quantify performance in terms of useful service life, it is suggested that we establish minimum standards for day and night time visibility with emphasis on wet pavement retroreflection and bead retention. These standards will be required to evaluate the quality grade of a paint objectively and to serve as reference in disputes.

TABLE 9: SUMMARY OF PROPOSED ACTION PLAN

Problem Area	Proposed Action*
1. Low quality conventional paints	. Develop performance specification . Regular update of designated source list . Modify striping equipment
2. Uncoordinated program	. Conduct pavement marking review meeting . Use a working group . Institute a pavement marking management system
3. Mechanism for evaluation and acceptance of new technologies and products	. Develop an economic model . Establish selection criteria . Use working group
4. Inadequate quality assurance procedure	. Training of inspectors . Update laboratory and field testing equipment . Emphasize performance rather than composition . Develop accelerated wear test
5. Temporary markings**	. Establish guidelines for the use of temporary markings . Develop procedure for the removal of pavement markings

* For review and consideration of the Operating Departments
** Item is outside scope of original project.

In order to maintain a high quality level, the performance standards and the designated source list (see also Section 6.4) must be updated regularly. The acceptance process should be carried out annually to avoid stagnation of new developments and competitiveness and to promote expedient introduction of new formulations and products.

Some quality improvements to traffic paint can be achieved by modifications of the application control on the striping equipment, for example, constant control of wet paint film thickness, matching old pavement delineations when repainting and the like. Also proposed is a study of drying time limitations as a function of quality (durability) and the effect it may have on striper speed and the no-track time of fresh laid paint.

7.3 Coordination of Program

Previous efforts to update pavement marking standards and to improve product quality and performance have produced only moderate or limited success mainly because of lack of coordination and documentation of the program. The product technology, evaluation, and procurement are handled by different offices or branches of the Ministry. Their choices and decisions have a major impact on pavement marking field application by the Districts and eventually the overall performance.

In order to be effective and stay abreast of new developments in the future, a conscience and concerted effort must be made by all Ministry operating departments to coordinate and document any technology evaluation, acquisition, and implementation activities. To this end, the institution of a working group is proposed to conduct regular review meetings and initiate and implement a pavement marking management system (PMMS) which operates on a normal planning, design, and implementation cycle. A data bank would be created as part of a quality/quantity control program. Such a computerized system will be used not only for logging data such as material usage, lane miles painted, manhours worked, etc., but also to input field performance and ultimately to be the key reference for product selection process and budgeting.

7.4 Evaluation and Acceptance of New Technologies and Products

The current practice for evaluation and acceptance of new technologies and products is lengthy and not very well defined. Confusion about selection criteria and general frustration amongst major paint manufacturers has all but eliminated competition for conventional traffic paints.

Before attempting to improve on the evaluation and acceptance procedure, it is important to have a clear understanding of the options for pavement marking procurement methods and their impact on the program.

The main options considered here for the selection and procurement process are:

Option 1

A lowest bid purchase from "recipe" (compositional specification) formulation. This option is considered unacceptable, as discussed in previous sections of this report, for the following reasons:

- decreases product quality,
- neglects new development,
- reduces competition,
- increases cost.

Option 2

A performance based, life-cycle cost purchase. A flow schematic of a proposed pavement marking selection procedure for Option 2 is given in Figure 5. The main differences between this proposed procedure and current Ministry practice are:

a) the new standard specifications emphasize performance rather than composition;
b) the selection criteria are formalized and address site-specific requirements;
c) the final selection is made on the basis of life-cycle cost rather than initial installation cost;
d) the supplier guarantees performance similar to the British "Kitemark" licensing scheme, the French "Homologation System", or the German "Release-Certification".

It is hoped that these differences will stimulate competition and quality improvements.

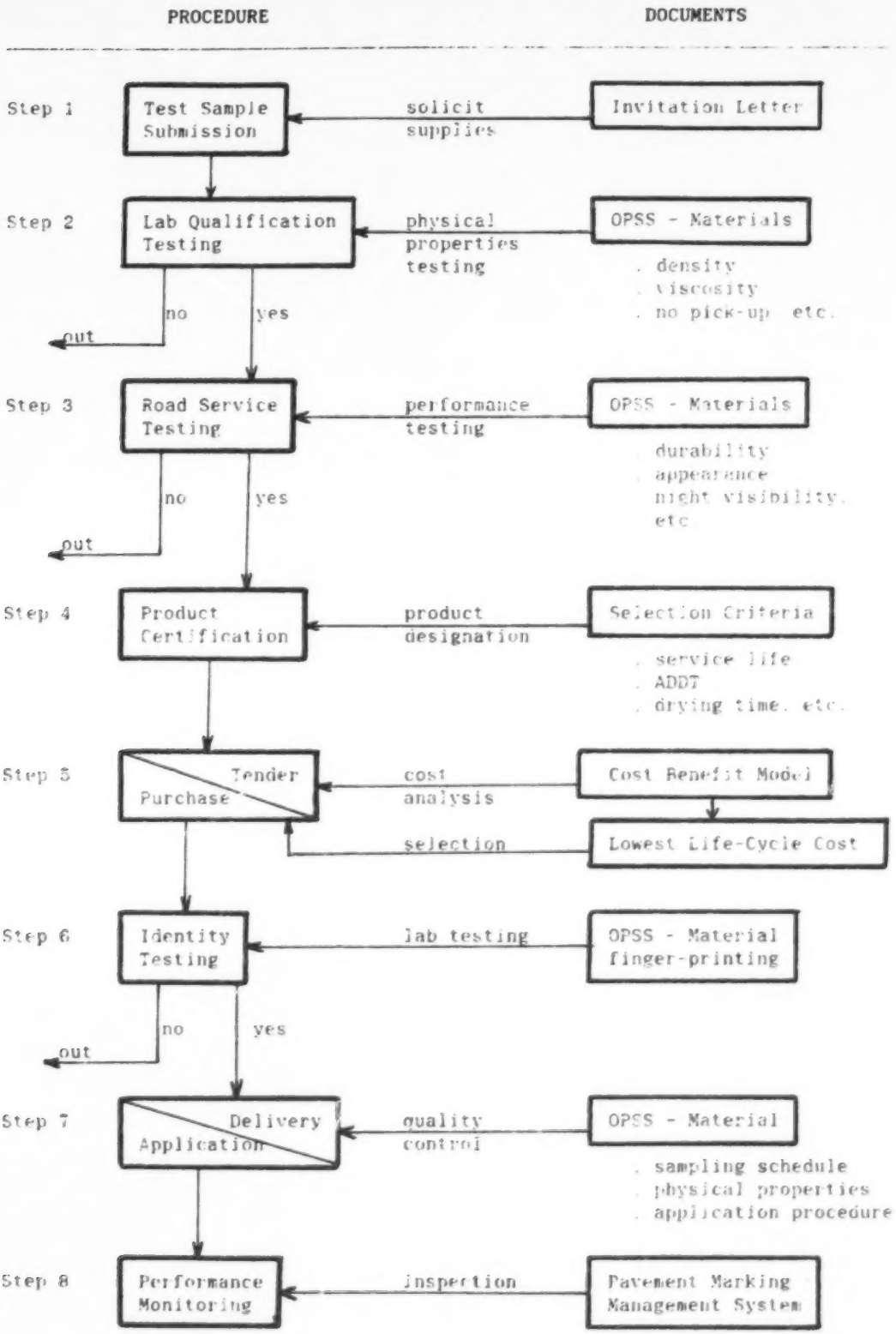


FIGURE 5: PAVEMENT MARKING MATERIALS SELECTION PROCEDURE

Option 3

A turn-key contract, where a qualified contractor will supply and install the required material from a designated product list and be responsible for maintaining a minimum performance for a given time at a fixed price.

Turn-key contracting of construction projects and maintenance activities, e.g. snow removal, has been practiced by many industries to good advantage. This technique is relatively new to pavement marking [64]; yet it is a simple and successful method and may be particularly appropriate for pavement marking systems that require specialized application equipment and technology (thermoplastics, two-component epoxy, etc.).

To clarify the mechanism for evaluation and acceptance, it is proposed that a group from the Ministry, with guidance from suppliers, should establish product selection criteria and develop a cost benefit analysis model tailored to Ontario's situation and requirements. The selection criteria will define site and application specific performance requirements, for example, drying time, ADT, service life, etc. The economic model will provide an objective method to determine the lowest life-cycle cost from field performance for a given set of selection criteria. The model will calculate life-cycle costs for any pre–qualified products using its expected service life based on test deck results and the in-place purchase price as per tender. The lowest life-cycle cost product will be chosen in compliance with Ministry selection criteria.

7.5 Quality Assurance

The current quality assurance procedure for both the conventional traffic paints and the more durable pavement markings are inadequate. There are no documented schedules, guidelines, or test methods for pavement marking inspection. The inspection is subjective and usually done by the local construction or maintenance engineer.

In order to achieve appropriate quality assurance, the following action is proposed for review:

- Development of a training program for on-site staff inspectors who will monitor quality and application of pavement marking materials as well as to evaluate and document field performance.

- Establishment of standards, schedules, and guidelines for field performance.
- Updating and development of laboratory and field performance test equipment and methods.

Because of the change to performance specifications, it becomes important to emphasize performance testing rather than composition. For this reason, confirmation of composition for an approved product may be carried out by a simple, highly automated and sensitive finger-printing process, which is suitable for paints such as the pyrrolysis gaschromatography (GC) technique.

To enhance the capability of quick, low cost durability testing, an accelerated wear test should be developed. Proposed for consideration here is the adaptation of Ministry test equipment for determining the aggregate abrasion and/or polished-stone value (British Standard Institution, BS812).

7.6 Temporary Markings

Although temporary markings are not within the scope of this research project, some actions are strongly recommended because of an urgent need to improve them and because of the close relationship of pavement surface preparation to removal of markings. Proposed is a review of temporary marking use, leading to the development of Ontario guidelines.

A most acute problem related to temporary markings is the removal or obliteration of pavement markings. This matter urgently needs to be addressed because improper obliteration techniques can produce a serious safety hazard, a situation which exists primarily on urban freeways.

The recommended action consists of the following two main phases:

a) Select from existing technologies (i.e., pavement marking removal equipment and technique) the most promising and appropriate procedures for the obliteration of traffic paints used in Ontario and demonstrate their use in full-scale field application. Guidelines or instructions will be prepared for proven equipment and techniques and issued for use in Ontario.

b) Develop alternative and improved methods for applying both the conventional traffic paints and the more durable pavement markings (e.g. thermoplastics and preformed tapes) which have already been introduced or will be used routinely in Ontario. Two examples are the design of a chip seal with chips of fine gradation and colour tone (e.g. 3M roofing shingle chips) and improved formulations of obliteration paint.

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